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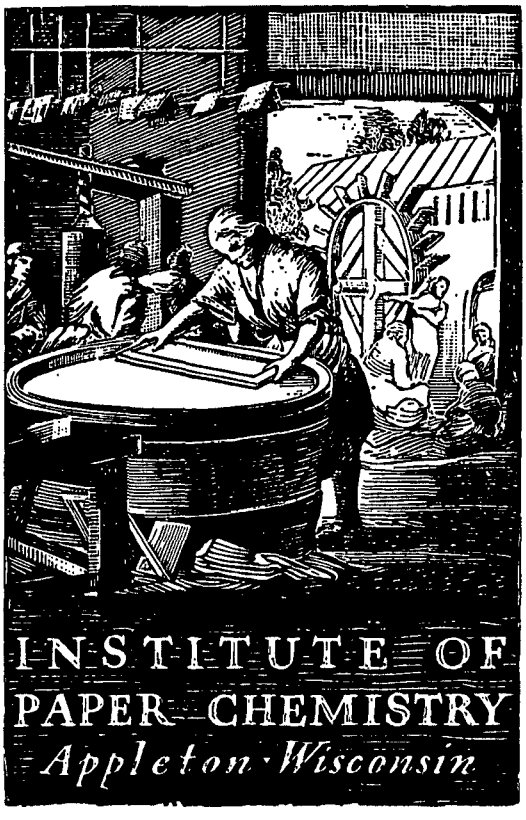

BARK AND WOOD PROPERTIES OF PULPWOOD SPECIES AS RELATED TO SEPARATION AND SEGREGATION OF CHIP/BARK MIXTURES

Project 3212

Report One

A Progress Report

to

MEMBERS OF GROUP PROJECT 3212

November 1, 1974

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

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Abitibi Paper Company Ltd.

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Appleton, Wisconsin

BARK AND WOOD PROPERTIES OF PULPWOOD SPECIES AS RELATED TO SEPARATION AND SEGREGATION OF CHIP/BARK MIXTURES

SUMMARY

There are a minimum of thirty to thirty-five tree species used as a source of fibers by the pulp and paper industry in the United States. The report that follows describes four pulpwood species and is the first of four such reports, each containing four tree species. Included in this first report is a description of the experimental procedures employed and a detailed description of the bark and wood properties of quaking aspen, sugar maple, white birch, and northern red oak.

Quaking aspen, based upon values in the literature and measurement data from two trees growing in northern Wisconsin, has an average wood specific gravity of 0.38 and a bark specific gravity of 0.50. Extractives levels were 3 and 15% for the wood and bark of aspen. The pulp yield for aspen bark was approximately 34%, and of this 34% (34 grams/100 grams of bark), approximately 10% (10 grams) was usable fiber, 2 grams were long thin-walled sieve tubes and 1% (1 gram) was sclereidlike material. Separation and segregation of aspen bark/wood chip mixtures appear feasible by several techniques including water flotation, compression debarking and pulping of wood/bark mixtures.

Sugar maple was found to have an average wood specific gravity of 0.59 and a bark specific gravity of 0.54. Extractives levels were low with wood having 1% and bark a low 6%. The inner bark of sugar maple has a high percentage of sclereids and very little fibrous material. Maple bark, when pulped, had a solids yield of 32-35%. However, when screened, only 8-12% of the solids were retained on 60 and 100-mesh screens. Despite large numbers of inner bark sclereids, only

minor amounts of sclereids were retained after screening. An alternative to pulping is to concentrate the bark in the small-sized chip fraction and then treat this fraction by either hammermilling or compression debarking.

White birch, based upon values in the literature and measurements made on Wisconsin-grown birch, had an average wood specific gravity of 0.49 and a bark specific gravity of 0.56. Extractives levels were similar to that of aspen with average levels for wood and bark of 4 and 17%. The outer bark of birch had a much higher bark strength and was more water repellent than the inner bark due to the phellem (cork) cells in the periderm. Morphologically, the inner bark is high in sclereids and lacks fibers and should be removed for some grades of paper. One approach that shows promise is to concentrate the bark by screening and then hammermill the fraction high in bark. Low inner bark strength makes the hammermilling procedure effective. Pulping white birch bark resulted in a solids yield of 32-35%. However, when screened, most of the material (85-89%) passed through the 200-mesh screen. The "through 200-mesh" material had 60-70% sclereids and 30-40% parenchymatous cells. Retained on the 60 and 100-mesh screens were primarily thin-walled sieve tubes.

Northern red oak had a wood specific gravity of 0.56 and an average bark specific gravity of 0.65. Bark extractives levels average 11.0%. Morphologically, the inner bark contains large numbers of sclereids and modest numbers of fibers. Pulping red oak bark gave solids yields of 25-30%. Screening of the bark pulp resulted in 80% of the solids and nearly all of the sclereids passing through the 100-mesh screen. The fraction retained on the 60 and 100-mesh screens contained 4.6 grams of fibers, 0.2 gram sclereids and 1.0 gram of sieve tubes per 100 grams of bark pulped. In addition to pulping the bark, another possible method of handling the bark problem in red oak is the use of compression debarking or water flotation to reduce bark levels prior to pulping.

INTRODUCTION

As more and more emphasis is placed on improved wood utilization and increasing numbers of companies turn to whole-tree chipping as a way of maximizing per acre fiber yield, efficient handling of bark and the problems associated with bark become imperative. Species-to-species, tree-to-tree, and within-tree differences in bark are considerable. This variation, coupled with differences between companies in species mixtures used, end product requirements and differences in investments in harvesting, debarking, and woodroom equipment, makes it evident that it is not possible to develop a "single solution" to the bark problem. The most useful service the Institute could perform, it appears, would be to provide interested companies with a concise package of data on each of the more important pulpwood species used in the United States. This would allow them to make appropriate decisions toward solving their specific bark problems.

To make the information as useful as possible, the format of each report is exactly the same. In addition, the information presented for a species is written in such a way that it is a complete study in itself and understanding the data is not dependent on reports on other species.

The purpose of the report that follows is to supply cooperating companies with information on the fundamental properties of bark (and wood) of quaking aspen, sugar maple, white birch, and northern red oak. The information was obtained from a comprehensive literature search combined with measurement data taken on a limited number of representative pulpwood-sized trees of each species.

TREE GROWTH AND BARK DEVELOPMENT

This section was added to the report to help the reader understand how a tree grows and how this affects wood and bark development. Introduced also will be the standard terminology used throughout the report.

Until a tree attains maturity, the enlargement of the crown and root system proceeds at a fairly rapid pace. After maturity, growth is slower although enlargement of some parts of the crown and root system continue throughout the life of the tree. The bole increases in diameter until the tree dies or is destroyed and some species may have a significant amount of bark growth.

Elongation of the bole and branches and the addition of new branches is carried on by the apical growing points and is called primary growth. Tissues arising from apical growing points are called primary tissues. These tissues determine the fundamental form of the tree.

As a tree adds growth through the apical growing points, however, it must also thicken to support the crown of the tree. Responsible for the increase in thickness is the cambium, found between the bark and wood throughout the tree. The cambium annually produces new bark and wood between the old bark and wood. Growth occurring in the cambium zone is called secondary growth and tissues originating from the cambium are called secondary tissues. These tissues add to the bulk of the plant and strengthen the stem.

A very young stem is protected for a short time by an epidermis which prevents loss of moisture and also contains stomatal openings to aerate tissues underneath. However, usually during the first year the epidermis is sloughed off.

Before this occurs, a new protective layer, the first periderm, is formed underneath it and protects the stem after the epidermis is ruptured. The periderm consists of three layers, the phellem (to the outside), the phellogen or cork cambium and the phelloderm (to the inside). The phellogen adds to the phellem and phelloderm through cell division and behaves like the cambium, becoming active during the growing season and dormant during the winter.

During the period while the primary periderm is functioning, thickening also proceeds from the cambium. Each year layers of new phloem (bark) and xylem (wood) are laid down, all enclosed by the primary periderm. In trees with smooth bark, such as birch and aspen, the first-formed periderm may persist for many years. In most woody plants, however, the first-formed periderm is shed in a few years, as it impedes growth, and is replaced by the formation of other layers of periderm deeper in the cortex. These later-formed layers of periderm are not continuous but in the shape of overlapping short arcs (lunes) which are active for only a short time. The bark outside these layers of periderm turns brown as it is cut off from the vital processes of the tree. The invasion of the phloem by the later-formed periderm marks the beginning of deep cork formation in trees and it is at this time that the outer surface of the bark becomes rough. In some species the brown outer bark is fairly thin because it weathers rapidly and is cast off while in other species much of this dead tissue is retained, resulting in a thick and deeply fissured outer bark.

The inner bark then consists of the region of secondary phloem from the cambium to the last-formed periderm. The outer bark refers to tissues from the last-formed periderm to the outermost surface of the bark. Tissues in the inner bark or secondary phloem are constantly being developed by the cambium and are

partly physiologically active while tissues in the outer bark are mainly physiologically functionless. Rhytidome is a term for the scalelike outer bark and is composed of periderm and dead secondary phloem which has been cut off by the last-formed periderm. Figure 1, taken from Chang (1), illustrates the tissues found in different kinds of bark.

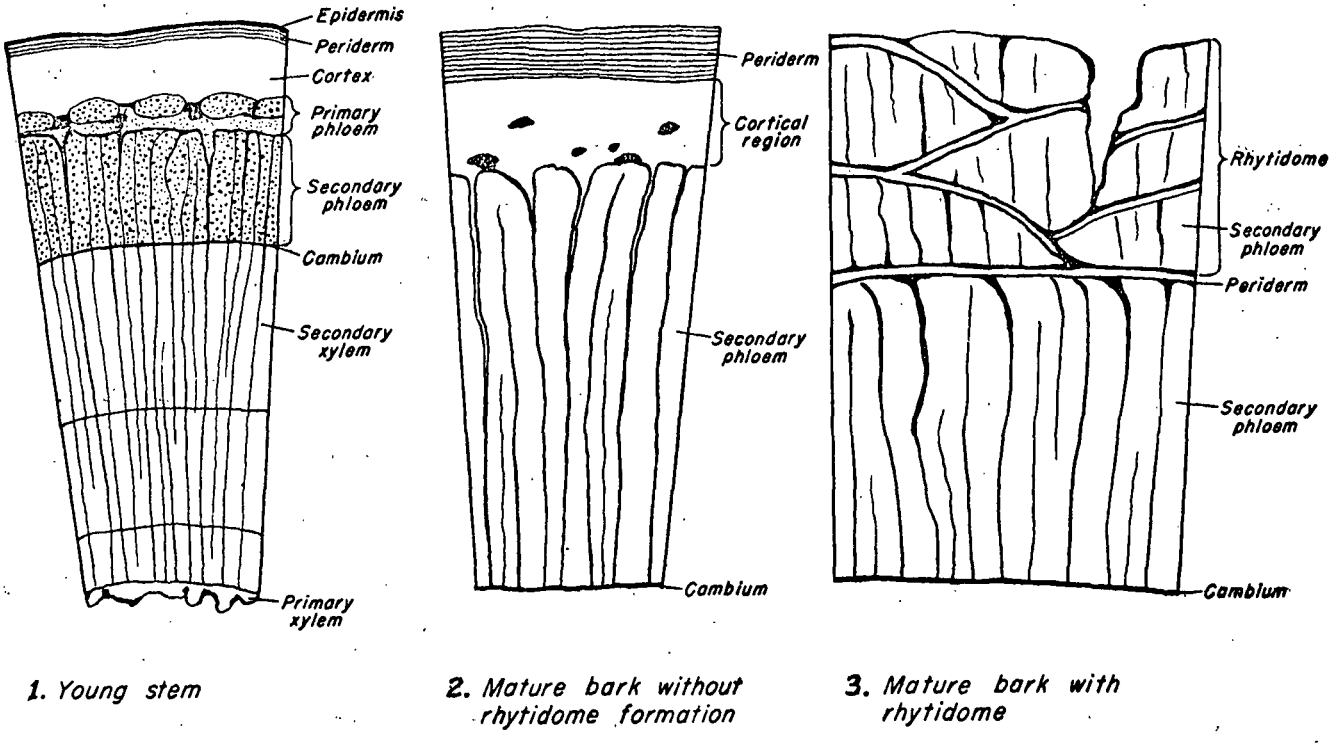

Figure 1. Diagrammatic Drawings Showing the Main Tissue in Different Types of Bark. (1) Cross Section of Young Branch or Stem. (2) Cross Section of Bark Having Persistent Cortex, such as that in the Middle-Aged Balsam Fir and Quaking Aspen. (3) Mature Bark with Rhytidome Formation

EXPERIMENTAL PROCEDURES

The experimental procedures employed have, as much as possible, been standardized and the same methods used for each tree species. To avoid repeating the descriptions involved, the information has been consolidated into a single section and is discussed below.

TREE SIZE AND SAMPLE LOCATION

Budget limitations made it imperative that tree size and sample location be standardized. Cooperating agencies and the Institute's field sampling crew were asked to sample trees 7 to 9 inches in diameter at breast height (4-1/2 feet). The wood/bark adhesion and bark strength samples were taken at or near breast height. In addition to breast high samples, most trees were cut and an additional 12 to 18-inch bolt was obtained from the area just below the breast high sample. The latter sample was used for wood and bark toughness, bark strength, wood and bark specific gravity, wood and bark basic density, and for water flotation studies.

SAMPLING PROCEDURES

Two different sampling procedures were used for obtaining undisturbed wood/bark adhesion samples. The simplest procedure involved merely cutting the tree and carefully removing a 5 to 6-inch bolt at breast height. The second, and slightly more complicated, procedure is demonstrated in Fig. 2. Using a chain saw, a series of horizontal and vertical cuts allows the removal of three wedge-shaped samples. The more complicated procedure was used when it was desirable to leave the tree standing and/or sample size and weight were factors in air freight shipment for speedy processing. For all wood/bark adhesion and

Figure 2. Satisfactory Test Samples were Obtained from Standing Trees Using a Small Chain Saw. Illustrated are the Steps Involved, Including: (A) Making a Series of Four Parallel Horizontal Cuts About Four Inches Apart with the End of the Chain Saw, (B) Making Two Parallel Vertical Cuts, Connecting the Horizontal Cuts, and on an Angle that Produced a Wedge-Shaped Sample, (C) Gently Lifting out the Sample with a Hammer

bark strength measurements, the samples were kept cool during shipment and measurements were made within 72 hours after collection. No special handling procedures were employed for the wood and bark samples used in making the other tests other than the procedures used to adjust the samples to a constant moisture prior to testing. This technique involves moistening the samples and then allowing the test specimens to equilibrate to a constant moisture content (approximately 20%) by placing the material in a constant temperature, constant humidity (50%) room for a minimum of 10 days.

PREPARATION OF SIMULATED CHIPS

To facilitate comparisons between species and to speed processing and handling in those tests where wood and bark chips were required, standard-sized simulated chips were used. For several tests, the standard-sized chips were further subdivided and, where this occurred, this was so stated in the procedure. The standard chips were 1-inch long (parallel to the grain), 0.6 inch wide and 0.2 inch thick and were prepared by subdividing a 1-inch-thick disk. The procedure involves cutting a 6/10-inch wide strip across the disk, starting at one edge and going through the middle of the disk. A guillotine cutter was used to further subdivide strips into heartwood, sapwood, and bark chips. Additional bark chip samples were prepared by making band saw cuts 6/10-inch apart around the margin of the disk and removing the bark chips with a chisel.

WOOD/BARK ADHESION MEASUREMENTS

Most early investigations into wood/bark adhesion used tests designed for bolts or standing trees. These were judged to be unsatisfactory for examining changes in chip samples. The wood/bark measurement technique used was developed in a previous group project (Project 2929) and measures shear parallel

to the grain on a small (3/16-inch x 3/16-inch x 1 1/4-inch) specially prepared test sample. The failure zone was controlled by making cuts in the test specimen from the bark side and the wood side with the distance between the cut being 1/8-inch and the cuts overlapping by 0.010 inch in the cambium zone region. The surface area of the wood/bark interface being tested was 0.0234 square inch or 0.151 square centimeter. Figure 3 illustrates several of the steps used in preparing the sample prior to testing in the Instron tester.

For testing, the specimens were mounted in an Instron testing machine as shown in Fig. 3D. The clamping jaws were 0.02-inch wide and were separated by a distance of 0.75 inch. Specimens were strained at a rate of 0.2-inch per minute. Nine specimens were tested for each tree on each testing date. Each specimen, after testing, was examined and the type of failure noted. Representative specimens of each species were immersed in ethyl alcohol immediately after testing for later morphological examination.

One important limitation of the IPC procedure for measuring wood/bark adhesion (and a limitation for all procedures presently being employed) is that, during the dormant season, when failure occurs in the bark, the magnitude of the test value is dependent upon the strength of the inner bark of the species involved. All that can be said about the values obtained during this period is that "adhesion in the cambium zone and in the bark and wood elements immediately adjacent to the cambium zone is in excess of the values obtained." The dormant season test values do, however, provide an indication of the difficulties that can be expected in bark removal during the dormant season.

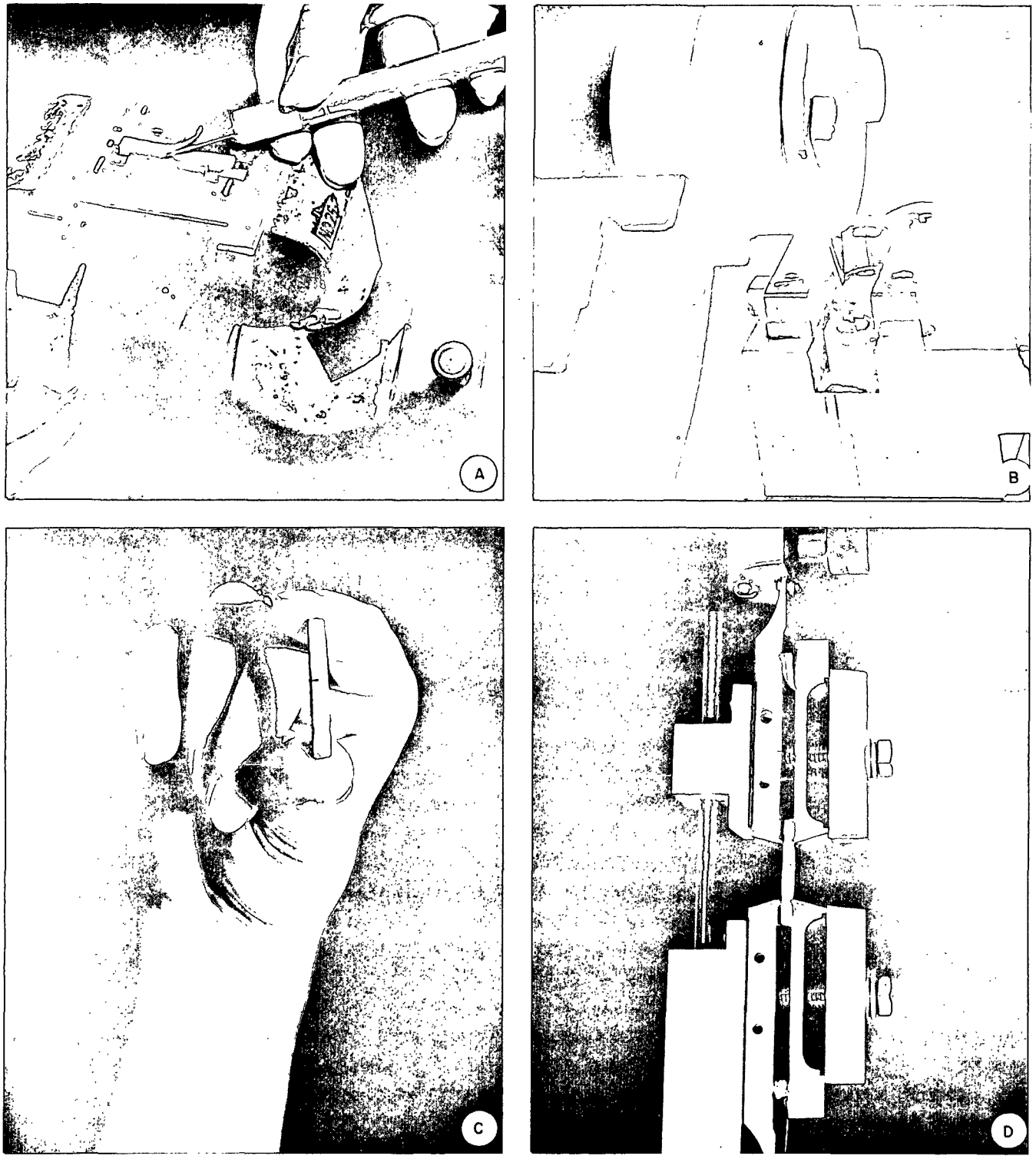

Figure 3. Small Test Samples Suitable for Use in the Instron Tester were Prepared by Cutting the Sample to Approximate Size on the Band Saw. The Samples were then: (A) Shaved to the Exact Dimensions, (B) Cuts Made Through the Bark and Wood to Cambium, (C) Removed from the Jig Used in Holding the Sample During Cutting, (D) Tested for Adhesion (Shear Parallel to Grain) in the Instron Tester

BARK STRENGTH MEASUREMENTS

Bark strength measurements were made using essentially the same procedures as used in measuring wood/bark adhesion. Test specimens were prepared as described for the wood/bark adhesion test with the exception that, when inner bark strength was being tested, the two cuts made from opposite sides of the test specimen were prepared so as to overlap in the inner bark zone. When testing the strength of the outer bark, the cuts were so located to overlap in the outer bark region. The location of the overlap of the cut was the factor controlling the zone of failure. The strength measured was shear parallel to the grain.

BARK TOUGHNESS MEASUREMENTS[1]

The brittleness or toughness of bark is believed to be important because it is expected to be related to the ease with which bark can be broken into small particles by hammermilling or similar procedures. The ASTM toughness test for wood is not suitable for use with small bark samples. After investigating 3 different methods of promoting rupture, the energy required to rupture a small bark or wood sample by bending with a force parallel to the diameter of the tree was selected. The specimens for the bending tests were cut to a width of 0.455 cm and long enough to permit a test span of 1.92 cm. The thickness of the specimens varied depending upon the bark thickness of the species being tested. The specimens were tested using a center-load beam test. Both the supports and loading ram were 1/8-inch diameter steel pins. The specimens were tested at a rate of 0.254 cm/min. The properties evaluated from the load-deformation curves were unit stress S, Young's modulus E, and elastic energy U:

[1]Toughness test developed by Roger Van Eperen and W. A. Wink of the IPC Paper Evaluation Group.

$$S = PL/4 \times c/I = 1.5\ PL/bd^2 \qquad (1)^2$$

$$E = PL^3/4ybd^3 \qquad (2)^2$$

$$U = S^2/18E \qquad (3)^2$$

where P = force at proportional limit

L = beam length

c = distance of outer fiber from neutral axis

I = rectangular moment of inertia about the neutral axis

b = beam width

d = beam thickness

y = beam deflection at P.

The elastic energy (U) for inner bark, outer bark, and wood is the value reported and is reported in terms of kg cm/cm^2. Because, during preliminary testing and development of the method, bark toughness (elastic energy) was found to decrease as the moisture content of the sample increased, all samples were tested after equilibrating at 50% RH for a minimum of 10 days (20% moisture, o.d. basis). Both bark strength and bark toughness will be examined and attempts made to relate the data to simulated hammermilling tests.

HAMMERMILLING TESTS

A hammermilling test procedure was developed for use with 1/2-sized (1-inch x 3/10-inch x 2/10-inch) simulated bark and wood chips. The objective of the test was to relate bark strength and bark toughness to a hammermilling type of action. A standard "Micro Pulverizer"[3] was modified to reduce the

[2]From Marks Mechanical Engineers Handbook, 6th edition, 1958.
[3]Pulverizing Machinery Company, Roselle Park, N. J.

severity of the action. Modifications included reducing the electric motor rpm from 3500 to 1725, removing four of the six hinged hammers, rounding the edges of the remaining two hammers to decrease the cutting action and increase the clearance between the hammers and the pulverizing chamber to 0.35 inch. A fine mesh herringbone type of screen was replaced with a screen with holes of 0.5 inch diameter. The air intake on the Micro Pulverizer was set at full open in order to move the sample through the pulverizer as rapidly as possible.

Samples were moistened and then equilibrated in a 50% RH room for 10 days prior to testing. The chips were fed through one at a time and the resulting material caught in a cloth bag. After all the chips had been fed through, the bag was removed and emptied on a series of soil screens. The screens include 5-mesh, 10-mesh, 14-mesh, 20-mesh, 28-mesh, and fines. Material on each screen was weighed and a percentage of the total calculated. This procedure was followed for both bark and wood chips of each species tested. In addition, each bark fraction was characterized as to how much inner and outer bark it contained.

SPECIFIC GRAVITY, BASIC DENSITY, AND MOISTURE CONTENT MEASUREMENTS

Specific gravity of small bark and wood samples was determined using a water displacement technique that is a modification of the TAPPI Standard Method, T 18 m-53. The sample specimens were soaked for approximately 24 hours prior to being processed in order to be certain that a maximum green volume was being measured. Results were expressed in terms of dry weight over green volume.

The basic density of small wood and bark samples at various moisture contents was determined using the pycnometer method with the chemical, heptane, employed as the displacement medium. The test specimens having various moisture contents were prepared by placing the required number of chips in small tightly

covered jars containing varying amounts of water. Chips were allowed to equilibrate for a minimum of 10 days and the basic density measurements were made following equilibration. First the density of the heptane was determined using a 25-ml pycnometer [(weight filled pycnometer − weight of empty pycnometer)/25].

When measuring the basic density of the moist chips, replicated determinations were made by subdividing the standard-sized chips into two or three pieces depending upon the number in each jar. One piece from each chip was blotted free of excess moisture and the two (or three) pieces making up the replication were weighed to get a wet weight. However, the inner and outer bark samples, and sometimes the total bark samples, were not subdivided because of the thinness and/or brittleness of the pieces. The chips from a particular replication were then placed in the pycnometer, heptane was added and the weight obtained on an analytical balance for the pycnometer containing the heptane + the chip replication. Usually a rough weight was obtained, the pycnometer removed, more heptane added and a final weight taken. This was necessary because of the rapid evaporation of the heptane. The replication was then removed from the pycnometer and placed in an appropriately marked coin envelope.

After all the samples were taken care of in this manner, they were oven dried for 24 hours at 105°C and an ovendry weight obtained. With this information, it was possible to calculate moisture content and density. Moisture content was calculated as (wet wt.-o.d. wt.)/o.d. wt. Density was calculated as $(cd)/[c-(b-a)]$ where:

a = weight of pycnometer + heptane

b = weight of pycnometer + heptane + chip

c = weight of chip (wet — before being placed in heptane)

d = density of heptane.

DWELL TIME MEASUREMENTS

Dwell time was measured to determine how rapidly the bark and wood of a particular species absorbs water and sinks. Approximately 50 grams of 1/2-standard-sized chips were weighed out (bark, heartwood, or sapwood) and allowed to soak for 1/2-hour in water. Chips were not allowed to soak longer because it was felt the loss of extractives might affect the dwell time. They were moved after this time and equilibrated for 10 days in a controlled humidity and temperature room (73°F, 50% RH). Containers were filled with water and allowed to come to room temperature for 24 hours prior to use. Chips were then placed in the water and the sinking chips removed after 5 minutes, 15 minutes, 1 hour, and 4 hours. The final test involved determining the ovendry weight of the fraction sinking after the various times.

BARK MICROPULPING PROCEDURE

Bark from breast high samples (4.5 feet) of the species involved was micropulped using the procedure of Thode, et al. (2). Cooking conditions were as follows:

Maximum temperature, °C	170
Time to maximum temperature, hours	2
Time at maximum temperature, minutes	65
Liquor analysis, g.p.l. as NaOH	40
Sulfidity, %	20
Liquor-to-wood ratio	10

As each vessel was removed from the oil bath, it was showered successively with steam, hot water and cold water. All vessels were then quenched in a container of cold water before opening. The contents of each vessel, together with rinse water to remove all chemicals and solids, was fiberized for two minutes in a Waring Blendor. The fiberized material was decanted on a sintered glass funnel and the liquid removed with a vacuum. Wash water was added and removed as required to clean the samples. An aliquot was removed, filtered on No. 1 Whatman paper and oven dried to provide yield data. The rest of the bark sample was kept in a wet state and put through a series of screens including 60-mesh, 100-mesh, 150-mesh and 200-mesh. The fractions that stayed on each screen plus the cellular elements that passed through all screens were examined for the type of cellular material they contained.

BARK AND WOOD PROPERTIES OF QUAKING ASPEN (Populus tremuloides Michx.)

SILVICULTURAL CHARACTERISTICS AND GEOGRAPHIC RANGE

The most widely distributed tree species in North America is the quaking aspen extending from Newfoundland and Labrador west across Canada along the northern tree limit to northwestern Alaska. The southern boundary extends from New Jersey westward to Iowa and then northwestward to British Columbia. It is also found in the mountains of western United States, in northern Mexico and in scattered locations in western Virginia and northern Missouri.

Growth and development of aspen is strongly influenced by soil conditions and, on medium and better quality sites, aspen can reach 70 to 80 feet in height by age 50. These soils are usually porous, loamy, humic and rich in lime. However, aspen can also be found on rocky, shallow soils, sandy areas and heavy clay soils.

The magnitude of importance of aspen in the Lake States is illustrated by the fact that the aspen-birch type is estimated to occupy 15.5 million acres in the Lake States Region (3-5) and the total acreage in the aspen-birch type in the northern forests of the United States is reported to be approximately 23.7 million acres (6).

WOOD AND BARK MORPHOLOGY

Wood (Xylem)

The heartwood of quaking aspen is nearly white to light brown with the lighter-colored and variable-width sapwood generally blending gradually into the heartwood. Aspenwood is generally straight grained, fine and uniformly textured. The wood (xylem) of quaking aspen is made up of fibers, vessels and ray cells. Quaking aspen is classified as a semiring porous wood because the

transition from earlywood (springwood) to latewood (summerwood) vessels is more or less gradual. As viewed in cross section, the early springwood vessels are solitary or in clusters of six or more. They are approximately 95-100 μm in diameter. These large vessels are immediately adjacent to the terminal band and are separated by 1-3 rows of fibers. The vessels in the latewood are smaller and average approximately 60-70 μm in diameter. They appear in smaller clusters and are separated by as many as 8-10 rows of fibers. There are between 85 and 180 vessels per sq mm in this species of wood.

The fibers in the xylem of quaking aspen average approximately 20-25 μm in diameter and 1.0 mm in length. They have a cell wall thickness of 2-3 μm. Gelatinous fibers, which have a cell wall thickness more than double that of normal fibers, are quite common in this wood species.

Bark (Phloem)

Aspen bark is variable in appearance from smooth and light colored to rough and dark. The normal bark is smooth and gray, with a typically waxy feel. The rough, dark bark apparently results from mechanical injury or attack by fungi and lichens [Kaufert (7)] or from a combination of both outside stimulation and natural formation [Chang (1)]. Morphologically, aspen bark can be separated into two parts, inner bark or secondary phloem and outer bark, consisting primarily in young and middle-aged trees of a continuously developed periderm and a cortical region. Rhytidome formation may appear in very old trees, principally at their bases. For pulpwood diameter trees (6-10 inches dbh), the bark of the bole typically consists of about 80% inner bark and 20% outer bark. However, on rough-barked trees the percentage of outer bark may run as high as 40%.

Inner bark includes the region of secondary phloem from the cambium to the last-formed periderm and is derived from the vascular cambium (secondary growth). Outer bark refers to tissues from the last-formed periderm to the outermost surface of the bark. This may include an epidermis (young stem), periderm, cortex, possibly primary phloem (the primary phloem cells may be destroyed or lose their identity in mature bark) and in very old trees may possibly include some secondary phloem if rhytidome formation has taken place. According to Chang (1), rhytidome formation is absent in young and middle-aged trees of quaking aspen. Figure 4 illustrates a cross section of quaking aspenwood and bark.

Anatomical Structure of Young Bark

The cell arrangement of the inner bark (secondary phloem) of quaking aspen is the same for both mature and young bark except for the rather late development of fibers in young bark. Although the scattered fibers may appear early, the formation of tangential bands of sclerenchyma cells has occurred as late as 6-8 years of age in branches (1).

The outer bark of young stems includes an epidermis which is one row of compact cells. The next layer, the periderm, includes several distinct layers. The widest area, the phellem, has uniform thin-walled rectangular cells, compactly arranged. This layer makes up about two percent by weight of the dry bark. The cortex occupies a greater portion of the bark in young stems than in the mature trunk. The outer part of the cortex has thick cell walls with large intercellular spaces. Cortical parenchyma forms the bulk of the cortex. In older branches, some cortical parenchyma become "lignified." Sclereid groups are absent in very young stems with scattered groups of fibers gradually appearing in older stems.

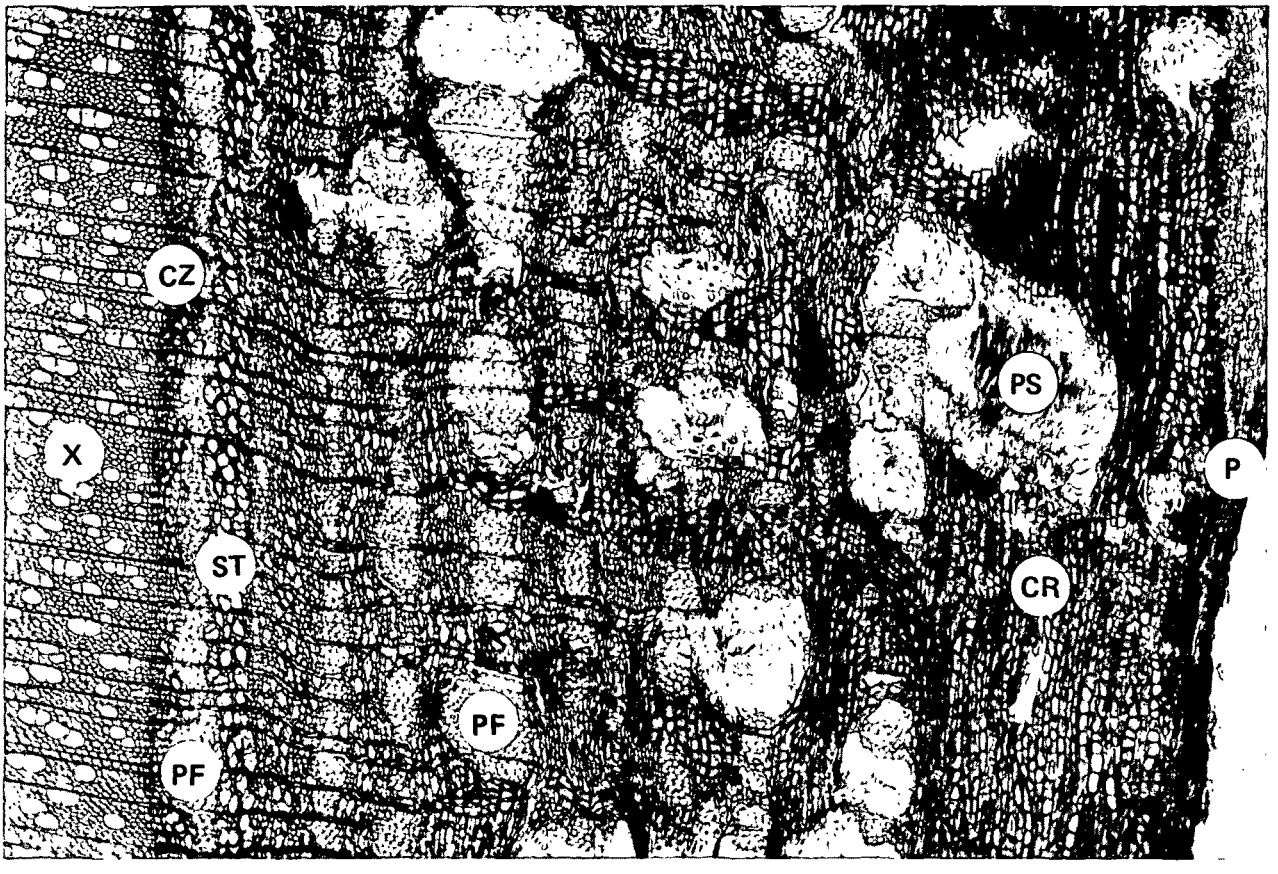

Figure 4. Cross Section of Populus tremuloides with (Left to Right) Xylem (X), Cambium Zone (CZ), Sieve Tubes (ST), Inner Bark, Cortical Region (CR), and Periderm (P). The Cortical Region and the Secondary Phloem are Merged Together by the Loosely Arranged Cortical Parenchyma, the Dilated Phloem Rays and Phloem Parenchyma Together with Scattered Groups of Sclereids (PS) and Phloem Fibers (PF). Magnification — 45X

Fibers in the primary phloem are in isolated groups and aligned tangentially encircling the phloem tissues. The fibers are smaller, with thinner cell walls and less "lignified" than those in the inner bark. Between the fiber groups, scattered sclereids appear.

Anatomical Structure of Mature Bark

As stated previously, the cell arrangement of the inner bark is the same for both mature and young bark, except for the rather late development of fibers

in young bark. The inner bark of quaking aspen is made up of sieve tubes, companion cells, parenchyma cells, sclerenchyma (phloem fibers and sclereids) and ray cells. The sieve tubes are large diameter (40-50 μm), thin-walled cells whose individual sieve tube elements are approximately 800 μm in length. They are normally surrounded by small diameter, thin-walled companion cells and parenchyma cells. The inner bark of quaking aspen is characterized by tangential bands, 2-10 cells in width, of phloem fibers. The bands may be discontinuous near the cambium zone. The fibers are approximately 18-20 μm in diameter. They have a cell wall thickness of 8-10 μm and narrow lumen of 2-4 μm. These fibers have an average length of approximately 1 mm. The homogeneous, uniseriate phloem rays are distributed uniformly throughout the inner bark. The inner bark often respresents about 80% of the bark [Hossfeld and Kaufert (8)].

The outer bark of mature trees differs from that of young stems. According to Kaufert (7), aspen bark remains permanently smooth unless injured. However, Chang (1) felt that unevenly differentiated periderm would naturally cause the formation of checks or fissures on the outer surface of the bark, but to a lesser degree than if injured.

Structurally, the last-formed periderm in the outer bark of mature trees, as in the young stem, consists of one layer of cork cambium (phellogen) and two to three layers of phelloderm and layers of cork (phellem). The periderm may be divided into three main types: (1) the thin-walled cells, which are rectangular to nearly square in shape and about 30 μm to 50 μm in diameter as shown on both cross and radial sections. This type of cell amounts to approximately 40% of the total periderm; (2) the thick-walled cells are about the same shape and size as the thin-walled cells with distinct simple pits and often containing a "resinous" substance; (3) the sclereids are often found in small groups more

or less tangentially connected and scattered at the outer part of the phellem in the older trunk. These "sclerified" cells occupy the smallest percentage of the total periderm, usually less than 10%, but the numbers can be quite variable. These three kinds of cell types in mature periderm have no definite pattern of distribution, although the thin-walled layers generally alternate with the thick-walled layers and the "sclerified" cells are often associated with the thick-walled cells.

The cortex in aspen retains its position from the young to the old trunk, and its cells have about the same contents as in the young stage, except for their size and abundance of contents. The cortex can occupy up to 7 to 9% of the total thickness of bark. The cortical region does not show distinct demarcation from the inner bark. These two parts are merged together by the loosely arranged cortical parenchyma, the dilated phloem rays and phloem parenchyma, together with scattered groups of sclerenchyma.

The distribution of phloem fibers decreases from the cambial zone toward the periderm. Phloem fibers make up 25% of the total inner bark with only 6% at the outer limit. The sclereids range from none in the greater part of the inner bark to 28% at the outer part of the inner bark. The percentage of sclereids in the total inner bark averages 15%.

SPECIFIC GRAVITY, EXTRACTIVES AND FIBROUS YIELD

Basic information on such bark properties as specific gravity, level of extractives, fiber yield and the presence of such morphological elements as phloem fibers and sclereids are expected to be useful in determining the need and

possible methods of separating and segregating wood/bark chip mixtures[4]. Whenever possible, data on bark have been compared with similar information on wood.

Specific Gravity

Specific gravity of bark and wood of quaking aspen has been measured by a number of individuals. The data exhibit considerable variation, partly due to genetic and geographic differences and in part due to measurement techniques[5] and different ways of expressing the data. Table I summarizes the information available and, whenever possible, information on bark is separated into inner and outer bark. Specific gravity is most often expressed as ovendry weight over green volume. It should be noted that several of the values in the above table are ovendry weights divided by ovendry volume and the last set of values by Erickson (15) are green weight divided by green volume. Information expressed in terms of green weight divided by green volume is particularly useful when examining the possibilities of liquid flotation as a means of segregating wood/bark chip mixtures. Information in this report under the section Water Flotation Behavior compares the basic density (green weight divided by green volume) of aspen at several moisture contents.

Specific gravity of aspen has been shown to vary geographically from north to south in Wisconsin (18) and for northern Wisconsin and the Upper Peninsula of Michigan an average specific gravity of 0.37-0.39 appears appropriate. There is little evidence of differences in specific gravity between heartwood and sapwood of quaking aspen.

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[4]Throughout this report the term separation has been used to designate separation or detachment of wood from bark while segregation has been used to indicate removal of either the bark or wood fraction from wood/bark chip mixtures.

[5]Increment core data, for example, tends to weight the center of the tree more heavily than the area near the cambium while disks and wedge-shaped samples provide representative values.

TABLE I

QUAKING ASPEN SPECIFIC GRAVITY INFORMATION

(Ovendry weight/green volume)

Wood		Bark				
Average	Range	Inner	Outer	Total	Range	Reference and Remarks
0.35						Isenberg (9)
0.35						Besley (U.S.) (10)
0.40	0.32-0.45					Besley (Canada) (10)
0.404	0.402-0.404					Pronin (diam. 6.6-10.5 in.) (11)
		0.40	0.49	0.48	0.45-0.50	Fournier & Goulet (12)
		0.369	0.536			Smith & Kozak (13)
0.388	(last-formed sapwood)	0.397	0.492	0.452		Lamb & Marden (14)
0.367	0.343-0.407			0.505	0.446-0.602	Erickson (15)
0.357	0.328-0.415			0.503	0.431-0.528	IPC determinations
0.42				0.63		Einspahr, et al. (16)
0.40				0.44		Einspahr, et al. (16)
0.449	(heartwood)	0.552	0.738	0.643		IPC 3212-5
0.420	(sapwood)					
0.324	(sapwood)	0.493	0.470	0.502		IPC 3212-8
0.455[a]	0.407-0.511			0.821[a]	0.720-0.890	Erickson (15)
				0.681[a]	0.611-0.727	Harkin & Rowe (17)
0.742[b]	0.670-0.819			0.955[b]	0.872-1.026	Erickson (15)
0.83[b]				0.98[b]		Einspahr, et al. (16)
0.75[b]				0.88[b]		Einspahr, et al. (16)

[a] Ovendry weight/ovendry volume.
[b] Green weight/green volume.

The specific gravity of the total (inner + outer) bark of aspen is higher than that of the wood with an average of approximately 0.50 being typical for aspen in northern Wisconsin. Most researchers have found the specific gravity of the inner bark to be less than that of the outer, although for the two trees that were examined in detail (IPC 3212-5 and 3212-8) which represent extremes in wood specific gravity, there is evidence that in some instances the specific gravity of the inner and outer bark may be approximately equal. Tree IPC 3212-8 had low wood and average total bark specific gravity and a very thin outer bark.

Tree IPC 3212-5 had a high wood specific gravity, high bark specific gravity and a moderately thick outer bark.

Conclusions drawn are that the specific gravity (ovendry weight/green volume) of quaking aspen bark, although variable, is heavier than that of the wood. The outer bark, when present in typical amounts as in bole chips from 20 to 50-year-old trees, has a higher specific gravity than the inner bark. Overall average values suggested for use in species comparison are 0.38 for wood, and 0.40, 0.55, and 0.50 for inner, outer, and total bark.

Extractives

Extractives in wood and bark are important because, when present in large amounts, they not only result in reduced yield of fibrous material but ultimately can be expected to result in paper machine "pitch problems." Recent needs to reduce total water use through closed white water systems are expected to accentuate problems in this area. No attempt has been made in this report to go beyond determining the total alcohol-benzene extractives. Such extractives information is expected to provide an appropriate indication regarding possible pitch problems when large amounts of bark are pulped. Further detailed examination of the types of extractives involved is recommended using specific bark sources if preliminary comparisons suggest pitch and yield problems may develop.

Considerable information exists on the alcohol-benzene extractives levels in the wood of quaking aspen. Much less is known about extractives levels in the bark of quaking aspen. Table II summarizes existing data and includes two aspen (IPC 3212-5 and IPC 3212-8) which represent typical variation in bark thickness and ratio of inner to outer bark for pulpwood-sized trees.

TABLE II

QUAKING ASPEN ALCOHOL-BENZENE EXTRACTIVES

Type of Material	Extractives, %	Sources
Wood	2.9	Isenberg (9)
Wood	2.8	Isenberg (9)
Wood	1.5	Isenberg (9)
Wood — 5-year-old trees	4.6	Einspahr, et al. (19)
Wood — 10-year-old trees	3.4	Einspahr, et al. (20)
Wood — 40+-year-old trees	3.5	van Buijtenen (21)
Wood	2.9	Rydholm (22)
Bark	15.6	Harkin & Rowe (17)
Bark — medium outer bark	13.1	IPC 3212-5
Bark — thin outer bark	21.7	IPC 3212-8

Quaking aspen wood is low in extractives and there is considerable evidence that young trees (2 to 5 inches dbh) have modestly higher levels of extractives than pulpwood-sized trees (6 to 10 inches dbh). For between species comparisons, an extractives level of 3% is suggested for the wood of aspen. The bark of quaking aspen has a considerably higher level of extractives than the wood. Preliminary comparisons made suggèst the inner bark is higher in extractives than the outer bark. This would mean, of course, that the ratio of inner to outer bark can be expected to have an influence on whole bark extractives levels. The average level of extractives suggested for use for the bark of pulpwood-sized aspen is 15%. This level of extractives, although fairly high, is not expected to be a serious problem except in those instances where high percentages of bark, particularly inner bark, have been concentrated in a particular chip fraction by screening or other mechanical techniques.

Fibrous Yield

Increasing emphasis is being placed on pulping bark rather than debarking bolts or segregating wood/bark chip mixtures. Important to determining the usefulness

of this approach with a particular species is determining the proportion of lignified cells that exist in the bark and that will survive normal cooking procedures. Also, it is important to determine what percentage of these cells will contribute in a favorable way to the resulting paper product. The two principal elements in the bark of aspen having an effect on pulp are sclereids and phloem fibers (sclerenchyma tissue).

Sclereids are short, thick, heavily lignified cells often found in clumps. When not fully cooked, as could occur in high-yield pulping, clumps of sclereids may cause so-called "fish-eyes" in certain grades (calendered) of paper. Estimates made of IPC macerated bark samples suggest that sclereids make up 11-15% of the total bark weight. According to Chang, 16.1% of the tissue elements in the inner bark are sclereids based upon examination of cross sections. These values seem in good agreement when one considers the inner bark is the zone of highest sclereid content. As will become evident in later comparisons, levels of sclereids in aspen are lower than levels in birch and comparable to levels found in northern red oak.

As described in the section on bark morphology, there occurs in the inner bark (secondary phloem) tangential bands of heavily lignified fibers described in the literature as phloem fibers or sclerenchyma fibers. These fibers are the principal bark elements expected to survive chemical pulping and contribute to overall pulp yield and sheet strength. Chang (1) estimated that 24.8% of the inner bark was composed of phloem fibers. Chase, et al. (23) reported that aspen bark from young trees, when pulped using a kraft pulping procedure, resulted in a screened yield of 35.8%. The fibers recovered from the bark were similar in dimensions to wood fiber being actually slightly longer and wider and thicker walled. Hunt and Keays (24), in pulping unmerchantable tops and branches, with and without bark,

found such material gave unbleached kraft pulps with greater permanganate numbers and screen rejects than pulp from corresponding boles. They felt material of this type could be pulped with wood from mature boles in limited amounts (5-10%) to give a satisfactory homogeneous pulp.

As a further check on pulp yield and the nature of fibrous material produced from aspen, 20 to 30-gram samples were pulped using the IPC Standard Kraft Micropulping Procedure. For a complete description of this procedure see the section on Experimental Procedures. Table III summarizes the results of this investigation. Micropulping of aspen bark resulted in a yield of 31 to 37% solids. When screened, the coarse screens (60 and 100 mesh) retained most of the fibrous material. The on 150-mesh screen had a high percentage of sieve tubes. The on 200-mesh and through 200-mesh screens had sieve tube fines and a high proportion of small sclereids. Figure 5 illustrates the type of material on the 60 and 150-mesh screens.

Based upon very limited numbers of bark sample observations, it appears that, for every 100 grams of bark that is pulped, about 34 grams of solids will result. Of this 34 grams about 10 grams (10%) of usable fiber, 2 grams (2%) of long, thin-walled sieve tubes and about 1 gram (1%) of sclereid-type materials will be produced. This assumes that only material on the 60 and 100-mesh screens will end up in and contribute in any significant way to the final product. The remaining material will be lost in washing and cleaning operations.

WOOD/BARK ADHESION

Wood/bark adhesion differences have been suggested as one of the reasons for differences encountered in the ease of debarking pulpwood species. The same factors influencing debarking of pulpwood are expected to influence debarking of

TABLE III

QUAKING ASPEN MICROPULPING INVESTIGATION

Data	Sample No. 3212-5	Sample No. 3212-8	Remarks
			Samples represent extremes in bark specific gravity
Yield, % solids	36.2	31.4	Third sample gave 36.9% yield
Fraction			
On 60 mesh, %	30.8	16.2	Fraction contained primarily phloem fibers (80-90%) with small percentages of sclereids (5-10%), crystalliferous parenchyma (< 5%), sieve tubes (< 5%) and parenchymatous cells (< 1%). The arithmetic average length of phloem fibers was 1.19 mm
On 100 mesh, %	5.4	5.8	Fraction contained large percentages of sieve tubes (40-50%), and phloem fibers (30-40%) with small percentages of sclereids (5-10%), parenchymatous cells (5-10%) and crystalliferous parenchyma (< 5%). The arithmetic average length of sieve tubes was 0.85 mm
On 150 mesh, %	7.0	8.0	Fraction contained large percentages of sieve tubes (30-40%), parenchymatous cells (20-30%) and sclereids (20-30%) with smaller amounts of phloem fibers (5-10%) and crystalliferous parenchyma (< 5%)
On 200 mesh, %	7.6	12.4	Fraction contained large weighted percentage of sclereids (50-60%), with smaller percentages of crystalliferous parenchyma (20-30%), parenchymatous cells (20-30%) and traces of phloem fibers (< 1%) and sieve tubes (< 1%)
Through 200 mesh, %	49.2	57.6	Fraction contained large weighted percentage of sclereids (50-60%) with smaller percentages of crystalliferous parenchyma (10-20%) and parenchymatous cells (20-30%)

wood chips. The approach taken in the study has been to obtain growing season and dormant season information on (1) magnitude of wood/bark adhesion, (2) morphological structures associated with wood/bark adhesion, and (3) reasons for differences between species in adhesion.

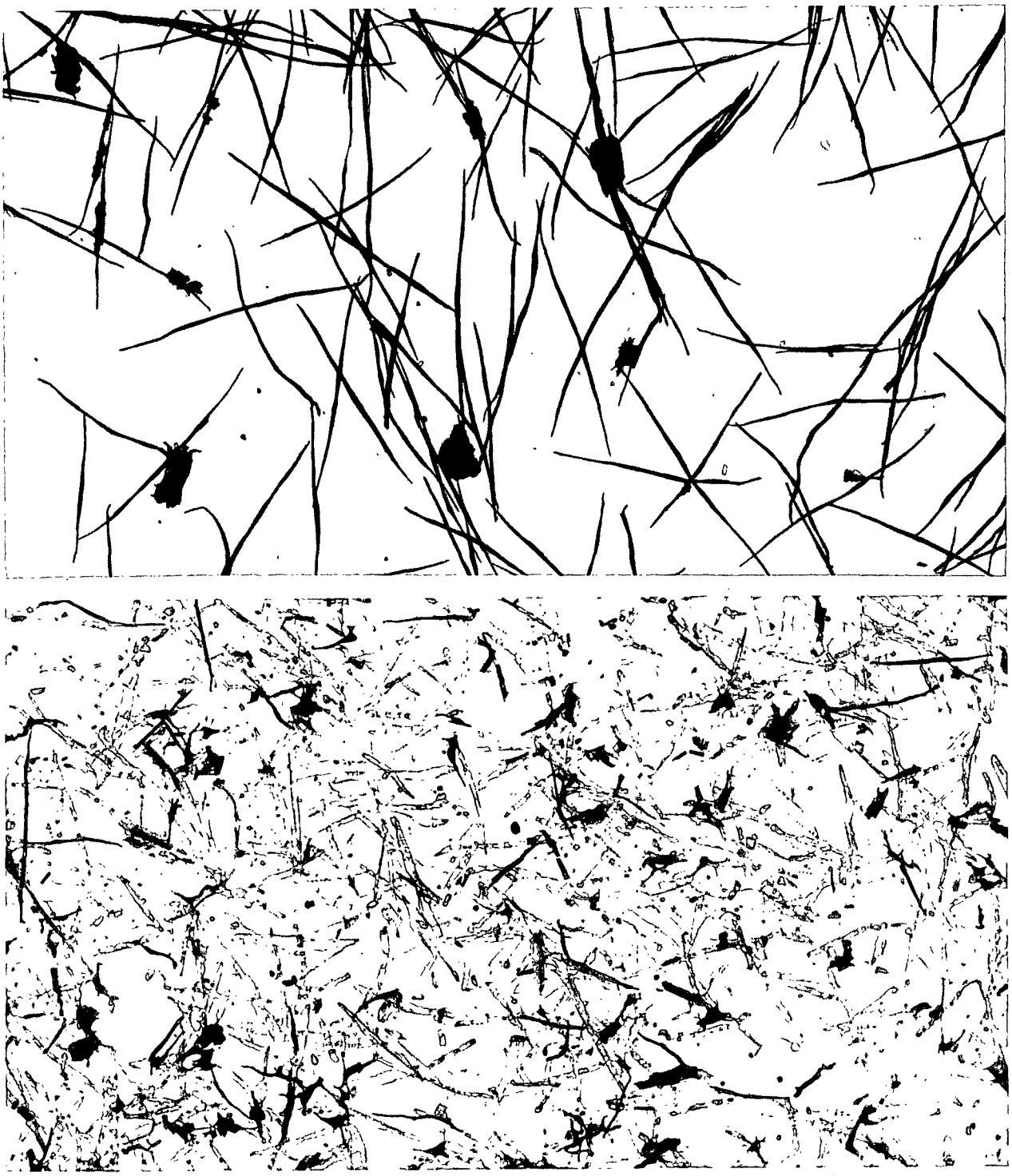

Figure 5. The 60-Mesh Screen (Top) Contained an Estimated 80-90% Phloem Fibers with Very Small Amounts (5-10%) of Sclereids. The 150-Mesh Screen (Bottom) Contained High Percentages of Sieve Tubes (30-40%) with Approximately 20-30% Sclereids. Magnification — 35X

Using the sampling and testing procedures described in the section on Experimental Procedures, shear parallel to the grain was measured for appropriately collected samples. Wood/bark adhesion in quaking aspen was studied extensively in Project 2929 (Progress Report One) and the work was not repeated but a summary of the results of earlier investigations follows.

Dormant season samples collected in March, April, and September revealed a cambium zone 3 to 5 cells in width and, when adhesion tests were made, failure quite consistently occurred in the inner bark in the sieve tube area between the two bands of phloem fibers nearest the cambium zone. During the growing season, wood/bark adhesion decreased and failure occurred either in the cambium zone or in the last-form nonlignified cells of the cambium zone or the last-formed nonlignified xylem cells. Figure 6 illustrates the changes in location of the zone of failure and Appendix Table XXVI gives the magnitude of wood/bark adhesion values involved. Included for comparison purposes are the results of wood/bark adhesion tests run on several other tree species. Adhesion values for quaking aspen averaged 6.4 kg/cm^2 during the peeling season and 11.4 kg/cm^2 during the dormant season.

As a result of measurement data taken on aspen and the other species included in Appendix Table XXVI, it became clear that dormant season wood/bark adhesion was related to inner bark strength and inner bark strength is in turn related to inner bark morphology. The presence of phloem fibers in the inner bark appears to be associated with high dormant season wood/bark adhesion. High numbers of sclereids seem to be associated with low dormant season wood/bark adhesion and low bark strength.

Separation (breaking the bond between bark and wood in a chip) is an important first step in the segregation (removal of bark particles from wood chips).

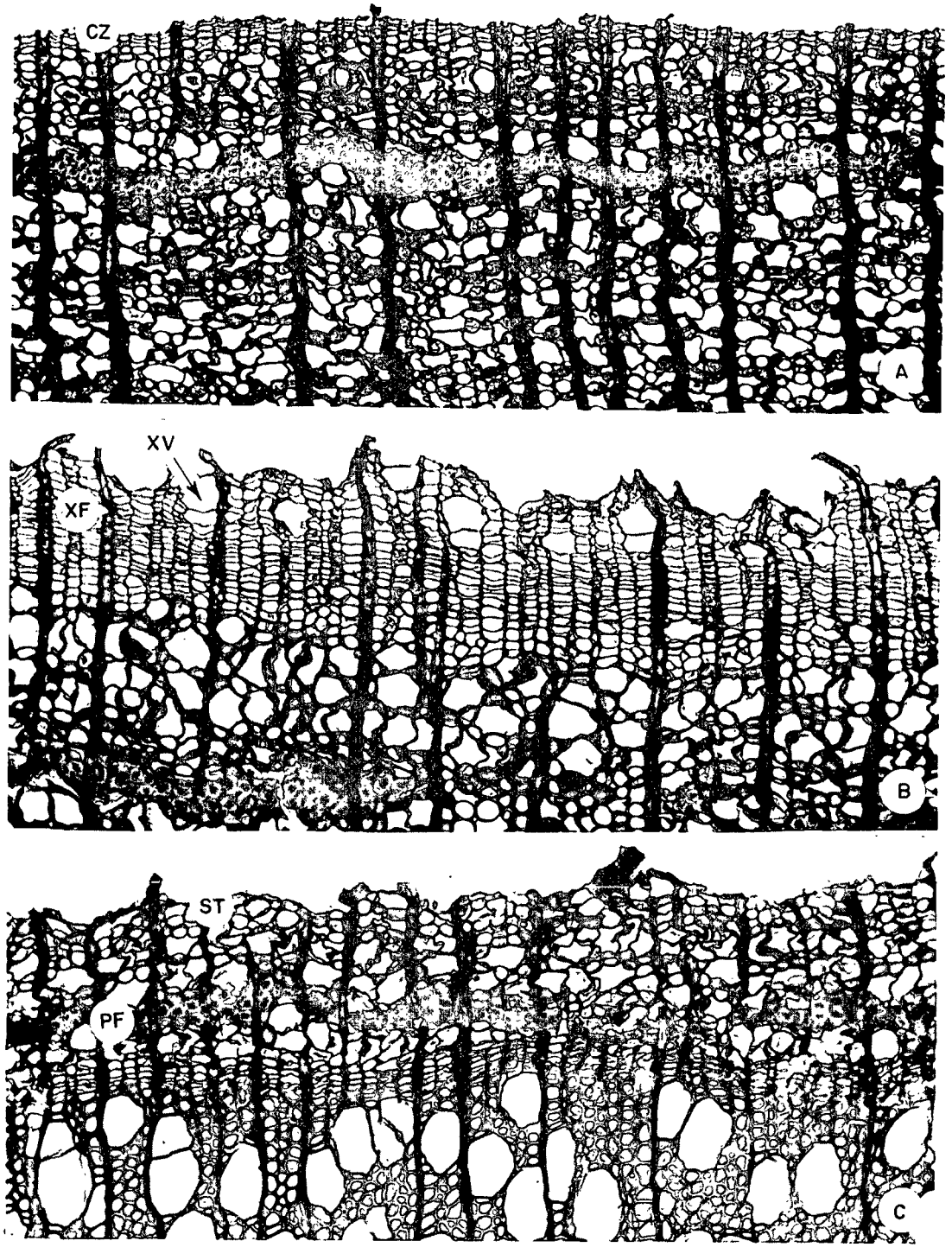

Figure 6. Illustrated are the Seasonal Changes in the Location of the Zone of Failure in Quaking Aspen. A — May 4 Collection, Failure Along Cambium (CZ); B — June 1 Collection, Failure in Newly Differentiated Non-lignified Xylem Fibers (XF) and Xylem Vessels (XV) and C — September 14 Collection, Failure in Phloem Sieve Tube (ST) Area Outside of Band of Phloem Fibers (PF). The Bark Appears in the Lower Area of Cross Sections A and B and in the Upper Area in Cross Section C

Separation during the growing season, when wood/bark adhesion is low, can usually be accomplished by the action of the chipper. During the dormant season, adhesion is greater and separation by chipper action is less successful.

The effect of chipper action on separation of dormant quaking aspenwood and bark was studied using the Institute's 41-inch, 4-knife Carthage Chipper[6]. Quaking aspen collected in November was chipped in an unfrozen condition. Separation at the wood/bark interface was good. Failure occurred mainly in the cambium zone and less than 10% of the bark chips had wood attached. Erickson (25) reported equally good results chipping winter-cut roundwood. The unloosened bark varied between 1.2 and 6.7% of the total material. Better separation was obtained with frozen wood although there were more fines produced.

Compression debarking appears to have some value, particularly when combined with a steam pretreatment (26). Most of the bark was concentrated in the smaller chip-sized classes after compression debarking. The percentage of wood chips with bark attached was reduced to 0.9% from 7.5% in the 5/8 to 1-1/8-inch class. It appears possible to chip bolts with bark attached, screen the resulting chip/bark mixture to concentrate the bark problem in one or two small-sized chip fractions and then use the compression debarking techniques on these fractions.

A number of methods to reduce adhesion were investigated in Project 2929 work. They included several chemical, thermal and biological methods. The use of green kraft cooking liquor at a temperature of 200°F and a treatment time of 60 minutes gave reduced adhesion. The main disadvantage was the high temperatures and long treatment time required. Chemical treatments were also investigated by

[6]Chipper runs reported as part of Project 2929 work.

Haas and Kremers (27) and, in their work, dilute acids were effective in reducing adhesion. The principal disadvantage of this treatment was the length of time required to effect separation, the discoloration of the wood of some species and the ineffectiveness of the treatment on dry samples.

Pressure chamber treatments also looked promising with reduced treatment time needed when temperatures were in excess of 250°F. Moist storage of chips at temperatures that encourage fungus attack of the cambium zone resulted in greatly reduced wood/bark adhesion at storage times as short as 15-20 days. Another promising approach was the use of microwave heating to create high temperatures in the moist interior of the chips. There was a moderate reduction in wood/bark adhesion at treatment times as short as one minute.

BARK STRENGTH, TOUGHNESS AND REACTION TO HAMMERMILLING

Bark strength and toughness measurements are included as part of the characterization of bark because it was felt that when these measurements are compared with the results obtained in wood/bark adhesion tests, with the difficulty encountered in conventional debarking and with bark morphology, the "why" of bark separation and segregation would eventually emerge.

Hammermilling has been widely used in bark utilization to prepare fractions for use as horticultural mulch, soil conditioners, and as additives to a number of types of products. Hammermilling has been suggested as one step in a wood/bark segregation procedure. A simulated hammermilling test was developed in an effort to relate the hammermilling of bark (and wood) to bark strength, toughness and morphology.

As discussed in the section on Experimental Procedures, bark strength measures shear parallel to the grain while bark toughness measures the energy required to rupture a thin specimen by a bending force perpendicular to the grain (parallel to the tree diameter). Table IV summarizes the bark strength and bark toughness tests made on the wood and bark of aspen. Fairly large differences were obtained in strength and toughness between outer bark and inner bark (and wood). This suggests it may be possible to remove most of the outer bark by hammermilling and screening procedures. Earlier investigations were made into bark strength as part of Project 2929 (Report Three). Included for comparison purposes are the bark strength values for a number of pulpwood species of interest (Appendix Table XXVII).

TABLE IV

SUMMARY OF STRENGTH AND TOUGHNESS MEASUREMENTS MADE ON WOOD AND BARK OF QUAKING ASPEN[a]

Material	Strength	Toughness
Sapwood	--	0.30
Inner bark	9.0	0.18
Outer bark	4.9	0.10

[a]Determinations made on two different trees.

Summarized in Table V are the results of the hammermilling tests run on aspenwood and bark. Little can be said about the relationships between bark strength, toughness, hammermilling and morphology with only the limited data on aspen to consider. Earlier wood/bark adhesion investigations (Project 2929) suggest, as data from additional species is tabulated, important interrelationships will become evident. Aspen bark and wood is believed to be intermediate in density, strength and toughness and the results of the hammermilling suggest the use of

TABLE V

SUMMARY OF HAMMERMILLING TEST ON QUAKING ASPEN

Tree No.	Type Material	Fraction Retained on Standard Screen[a], % 5 Mesh	10 Mesh	14 Mesh	20 Mesh	28 Mesh	<28 Mesh	Remarks
3212-5	Bark	26	28	14	9	8	15	High proportion (50-75%) of bark on 5, 10 & 14-mesh screens is inner bark, mostly outer bark on 20, 28 & < 28-mesh screens
	Heartwood	73	16	5	2	2	2	
	Sapwood	78	14	4	2	1	1	
3212-8	Bark	24	24	16	12	9	15	50-80% of bark on 5, 10 & 14-mesh screens is inner bark. Mostly outer bark on 20 & 28-mesh screens & in fines
	Sapwood	78	14	4	1	2	1	

[a]Standard soil screen sizes; 5 mesh has 5 wires per inch and an opening of 4.00 mm, 10 mesh has 10 wires per inch and an opening of 2.0 mm, 14 mesh has 14 wires per inch and an opening of 1.168 mm, 20 mesh has 20 wires per inch and an opening of 1.00 mm, and the 28-mesh screen has 28 wires per inch and an opening of 0.589 mm.

this technique followed by screening can be expected to result in only modest reductions in the levels of bark — if for example, by preliminary screening chips containing 40% bark are produced[7]. When such a mixture is hammermilled and the fractions retained on the 14-mesh screen are recovered and the material passing through the 14-mesh screen is used for fuel, the result would be a 5% loss in wood and a 34% reduction in bark with most of the bark removed being outer bark. The resulting mixture would have 32% bark, and 68% wood. Since much of the bark remaining is inner bark and has a fairly high percentage of usable fibers, the presence of inner bark will result in only a modest decrease in pulp yield. Removal of the outer bark means the removal of some of the sclereids. However,

[7]Arola and Erickson (26) reported in their work with aspen that their 3/16-3/8-inch chip-size class was 54.9% free wood, 44.6% free bark, and 0.5% wood/bark attached.

in view of the amount of inner bark still present, there would remain something over half of the original sclereid population. Better results are anticipated for species with weak bark and tough wood. Figure 7 illustrates the effect of hammermilling on the wood and bark of quaking aspen.

WATER FLOTATION BEHAVIOR

One possible method of segregating wood/bark chip mixtures is by water flotation procedures. Knowledge of the flotation characteristics of wood and bark is also expected to be important when certain types of chip washing procedures are employed. Earlier investigations into water flotation segregation (Project 2977) revealed that chip size, specific gravity, moisture content and rate of moisture uptake were factors in the flotation behavior of bark and wood chips. Budget limitations do not permit examination of all the factors involved and, as a result, the influence of chip size has been eliminated from the variables considered.

Two procedures were used to examine the water flotation behavior of wood and bark. One procedure involved measuring the density[8] (green weight divided by green volume) of simulated chips at a number of different moisture contents. The second technique involved measuring the rate of moisture uptake and sinking of wood and bark chips in what have been designated as "dwell time" studies.

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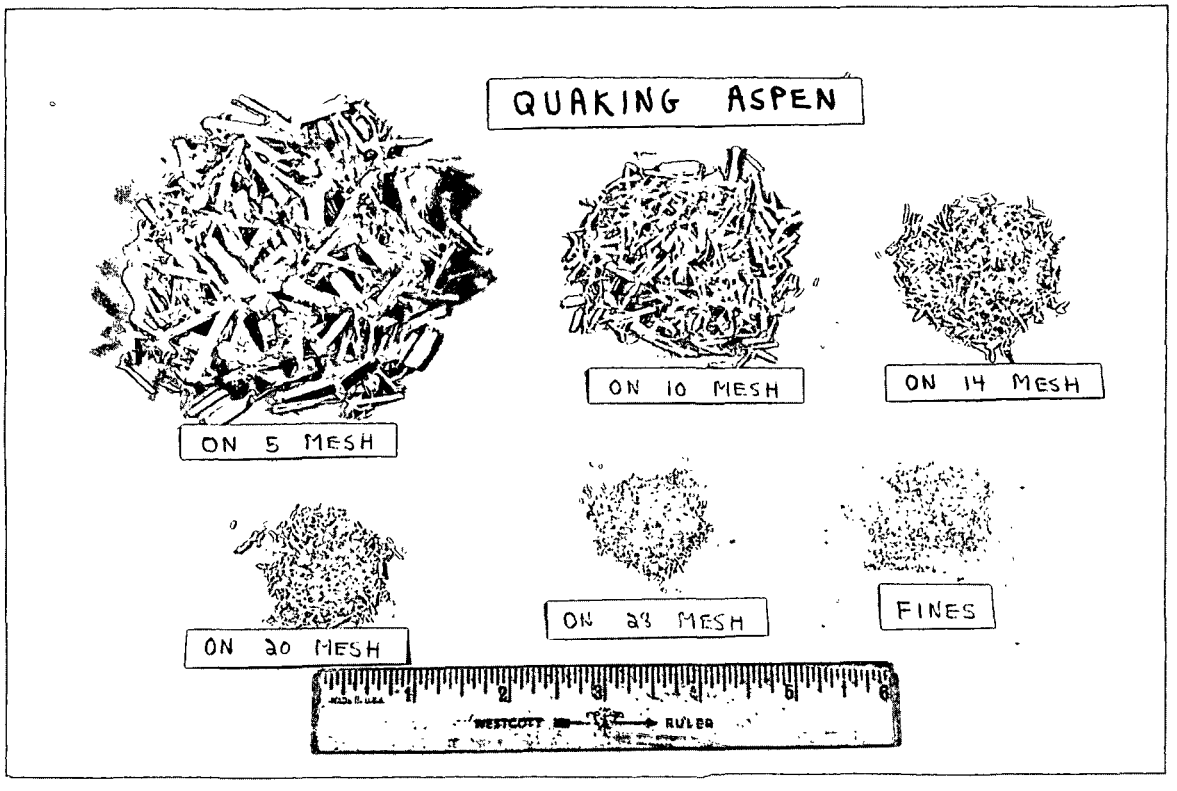
[8]The term density is used in this report to indicate the weight of wood and bark samples and is expressed in the terms of greem weight divided by green volume. This is in contrast to the term specific gravity, which also is an expression of the weight of a sample, but in this case it is in terms of dry weight divided by green volume.



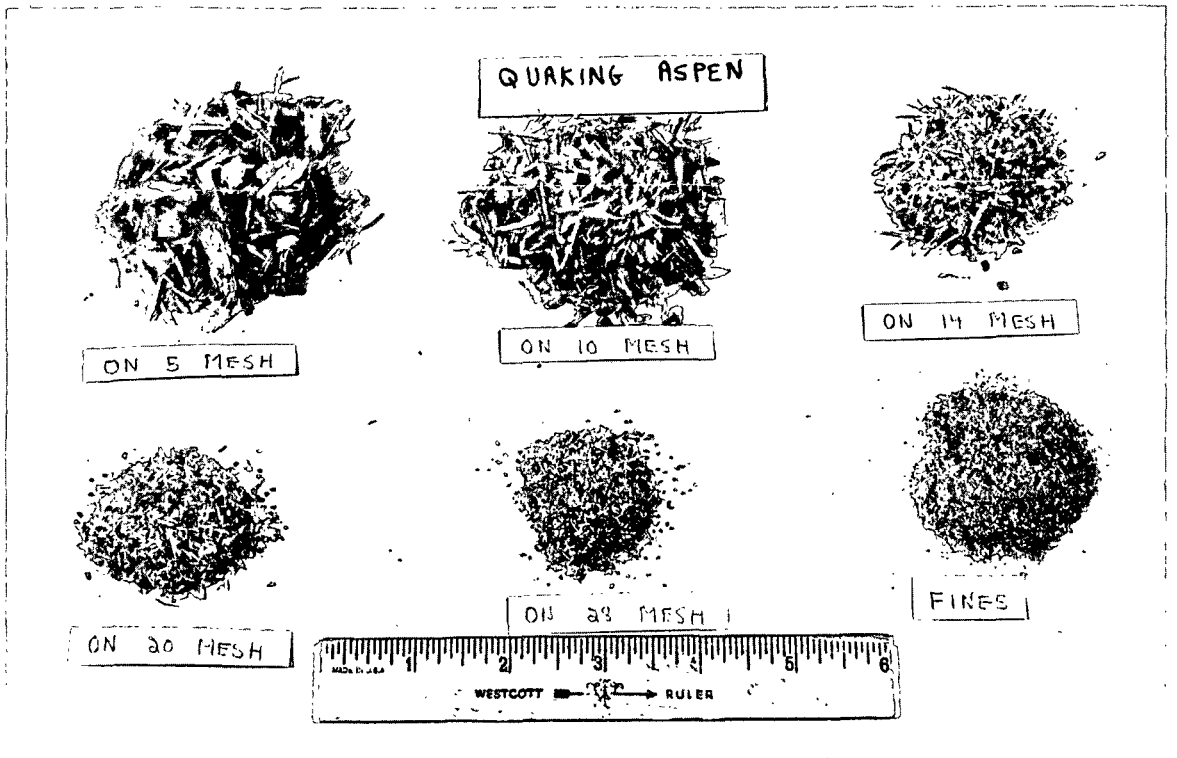


Figure 7. Illustrated is the Effect of Hammermilling on Quaking Aspenwood (Top) and Bark (Bottom)

Density Determinations

Simulated chips were used in determining the relationship between moisture content and density of bark and wood. Wood and bark from two quaking aspen trees (IPC 3212-5 and 3212-8) were used in making the determinations. The moisture content of the chip samples was adjusted by equilibrating in small jars to which had been added appropriate amounts of water. The extremely accurate pycnometer method described in the Experimental Procedures was used in determining density. The wood samples used included both heartwood and sapwood and, in the preliminary plotting of the wood data, it became apparent that no density differences existed between the two types of wood. As a result, the data were handled as a single population. Bark samples used were "whole bark" samples, a combination of both inner and outer bark. Small chips of inner and outer bark were also tested. The inner bark tended to have lower density than the outer bark and there were indications that at high moisture content the inner bark chips would behave like wood under flotation conditions.

Figure 8 illustrates the relationship that was found between moisture content and density. The linear relationship shown was obtained by fitting the least squares regression line through the data. The dashed lines are two standard deviations above and below the average values. The standard deviation of the regression line is considerably less than would have been obtained if conventional mill-run chips had been used for the water flotation studies, because the simulated chips were uniform in size and shape, had a uniform level of moisture and were relatively free of knots, reaction wood, etc. Water segregation is believed to be possible when one fraction has a density of less than one and the other greater than one at a specific moisture content.

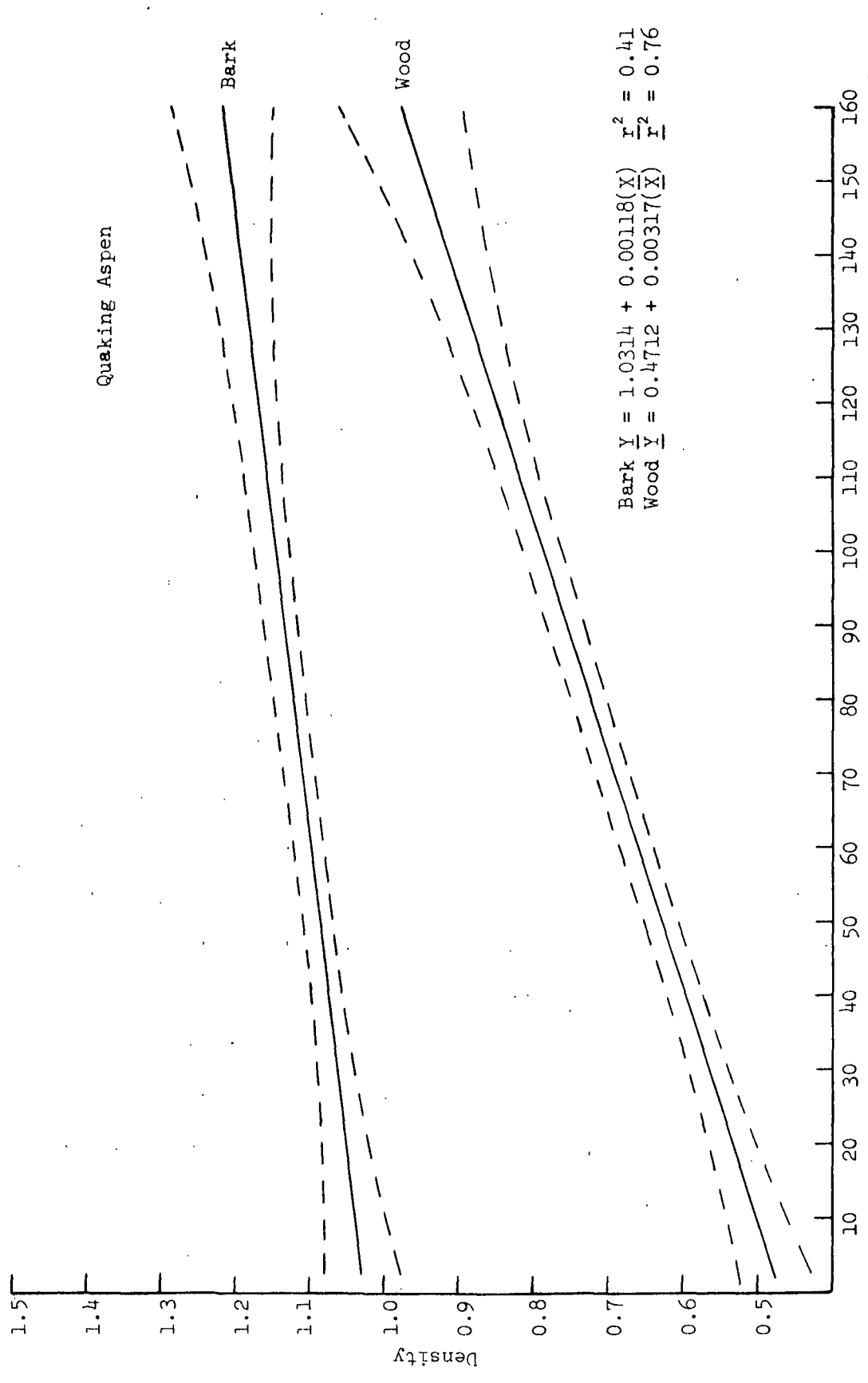


Figure 8. Illustrated is the Relationship Between Basic Density and Moisture Content for Quaking Aspen. The Dashed Lines are Two Standard Deviations Above and Below the Mean

The data indicate that at moisture contents above 20%, most whole bark chips could be expected to sink (density greater than 1). Aspenwood, on the other hand, at moisture contents of less than 140% would be expected to float. This would indicate there is a considerable range in moisture content where segregation of wood/bark chip mixtures is possible. Similar density differences were reported by Julian, et al. (28) in their density gradient column work using conventional aspen chips. Water flotation studies by Einspahr, et al. (29) and the results of Project 2977 with conventional-shaped aspen chips, further confirms the usefulness of wood density information at varying moisture content as a method for examining the flotation behavior of a tree species. The bark and wood density data indicate that at moisture contents of 20 to 140%, bark will sink and wood will float and that satisfactory segregation of the two fractions should be possible. Work with aspen chips in Project 2977 confirm these observations but the results, although promising, are less clear cut when conventional chips are used than the density regression lines suggest. The reasons are several. With conventional chips not all bark chips are total bark (inner + outer bark). Some are all outer bark, some are mostly inner bark and some have wood attached. Also, the moisture content of outer bark is often less than that of inner bark when conventional chips are used. Air entrapment in bark can reduce bark specific gravity and the presence of reaction wood and stain can greatly increase wood specific gravity to the point that a certain part of the total sample will not behave as expected. This is the reason for the wood loss and bark contamination information found in the literature when density measurements suggest good segregation should take place.

Dwell Time Investigations

An investigation of dwell time involves nothing more than taking wood and bark chips at some standard moisture content, placing them on a water surface and observing the time it takes the material to pick up enough water to sink. Information on dwell time is useful because moisture uptake rate could have a considerable influence on the success of a segregation procedure (or chip washing procedure) and would provide information on the rate at which segregation could be expected. Bark of aspen, because it takes up moisture very rapidly, has a relatively short segregation time. For other species, where specific gravity and density of the wood and bark are similar, and moisture uptake is similar, considerable difficulty in segregation can be anticipated. Time required for chip samples to sink decreases as the sample moisture content at the start of the trial increases.

Half-sized simulated chips (1 x 0.3 x 0.2 inches) were used in the dwell time tests. Prior to testing, the samples were equilibrated in 50% RH and had a moisture content of approximately 20% (ovendry basis). Table VI summarizes the results for quaking aspen and illustrates the kind of variability that can result when two different bark types are involved. Previous experience with aspen segregation indicates that, when samples are tested that have a starting moisture content of 90 to 100% (ovendry basis), dwell times as short as 5 to 10 minutes provide useful segregation results.

DATA INTERPRETATION

Based upon observations made on the bark and wood of quaking aspen, it appears that the bark of quaking aspen can be handled in a number of different ways. Bark morphology (moderate numbers of bark fibers, and relatively few

sclereids), specific gravity, extractive levels and the character of the bark fibers suggests that pulping bark/chip mixtures would be feasible. Chase, et al. (23) presented pulp yield results that seemed to confirm IPC observations made on the fibrous material produced from aspen bark.

TABLE VI

SUMMARY OF DWELL TIME RESULTS FOR QUAKING ASPEN[a]

Sample No.	Time Interval, min	Sinkers, %	Floaters, %
IPC 3212-8 Sapwood	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-8 Bark[b]	after 5	2.5	97.5
	15	7.6	92.4
	60	30.5	69.5
	240	79.0	21.0
IPC 3212-5 Sapwood	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-5 Bark[c]	after 5	56.2	43.8
	15	74.7	25.3
	60	81.3	18.7
	240	96.9	3.1

[a] Starting moisture content 20%.
[b] Bark thin – mostly inner bark and very little outer bark; specific gravity – 0.50.
[c] Bark typical of 25-year-old tree with moderately thick outer bark, rough and fissured; specific gravity – 0.64.

Moisture uptake, specific gravity and density differences between bark and wood suggest that aspen bark/wood chip mixtures could be segregated by water flotation procedures. These observations have been confirmed by several other investigators (29-30). Satisfactory separation and segregation have been obtained with aspen by Erickson (25) and Arola (31) using compression

debarking techniques. Best results have been obtained by first steaming the bark/chip mixture prior to compression debarking and then mechanically treating the upgraded mixture to further break up the bark. The last step is to screen the mixture to remove the bark fines that were created [Arola (31)].

The outer bark contains little in the way of fibers but does have scattered sclereid groups. The greatest concentration of fibers are found in the inner bark and the greatest number of sclereids are located in the outer part of the inner bark. Screening bark/chip mixtures to concentrate the bark in the small-sized chip fractions, then treating the fractions high in bark by compression debarking or hammermilling combined with screening or water flotation or a combination of several of the above methods could be used to further upgrade chip quality.

The degree of separation of bark from wood by the action of the chipper appears to vary with the tree species involved, size of wood, time of year and whether the material is frozen or unfrozen. Erickson (25) studied the influence of chipper action on the separation of bark and wood and observed that better separation occurred in the winter when the wood was frozen. Chipping of frozen wood was found to create additional amounts of fines. Hooker, working with sugar maple, found no apparent difference between types of chippers but found that smaller diameter bolts resulted in a greater percentage of chips with bark attached. Observations on ten previously investigated species (Project 2929) seemed to indicate that dormant season separation was influenced by wood/bark adhesion, bark thickness, and wood density. Thin-barked species with low wood specific gravity, like spruce, exhibited low bark/wood separation due to chipper action, whereas thick-barked high specific gravity species, like oak, had fairly complete separation. How universally this trend, based upon observations

or relatively few different species will hold, remains to be seen. Erickson's observations on frozen wood seem consistent with the above general pattern of results.

Pulping aspen bark appears feasible in certain situations. Based upon IPC observations, about 10 grams of usable fiber and 2 grams of long, thin-walled sieve tubes will be recovered from every 100 grams of bark pulped. Only about 1 gram of sclereidlike material will survive the pulping and cleaning operations which indicates a rather minor problem with this type of material.

The conclusion that can be drawn from the aspen information is that there are a number of ways that the bark problem can be handled which is fortunate. Whether a company decides to pulp all the bark or make a "quick and dirty" clean-up prior to pulping a chip/bark mixture having six to ten percent bark will very likely be decided by such factors as end product requirements, digester capacity, recovery for furnace capacity and/or pulp cleaner capacity. How much bark you remove and how you do it needs to be handled on an individual mill basis, taking into account the many trade-offs involved.

RELATED LITERATURE

During the process of reviewing and assembling the information on the bark and wood of aspen, a number of papers containing related information were reviewed. These papers are described in the paragraphs that follow. Some of the literature cited on specific gravity of bark and wood (Table I) also contained information on moisture content. These included papers by Besley (10), Erickson (15), and Smith and Kozak (13).

Thickness of quaking aspen bark was also covered in the previously cited article by Smith and Kozak. One addition reference in this area is: Hale, J. D. Thickness and density of bark (32).

An additional reference on seasonal variation in wood/bark adhesion is: Wilcox, H., Czabator F., and Firolami, G. Seasonal variations in bark-peeling characteristics of some Adirondack pulpwood species (33).

There were a number of articles on segregation of chip/bark mixtures. They include: (1) Hudson, L. E. Segregation of aspen wood chips from bark chips by the Cartesian Diver principle (34). (2) Plahutnik, F., Jr. Improvement of pulpwood yield. Application of the Cartesian-Diver principle to wood-bark chip mixtures (35). (3) Robins, D. E. Beneficiation of wood-bark chip mixtures by the Cartesian-Diver principle (36). (4) Sturos, J. A. Determining the terminal velocity of wood and bark chips (37).

BARK AND WOOD PROPERTIES OF SUGAR MAPLE (Acer saccharum Marsh.)

SILVICULTURAL CHARACTERISTICS AND GEOGRAPHIC RANGE

Sugar maple extends throughout the eastern half of the United States, excluding the South Atlantic and Gulf Coastal plains, and into southeastern Canada. It is one of the largest and most important of the hardwood species in this area. The Lake States, Ohio, Pennsylvania, New York, New England, the southern Appalachians and Canada contain most of the important stands.

Loam soils, fertile, moist, and well-drained, support the best development of sugar maple. Yield and quality of stands increase as soil fertility and moisture conditions improve. Height growth, 70 to 110 feet, ceases or become negligible after 150 years, although sugar maple can reach 300 to 400 years of age.

WOOD AND BARK MORPHOLOGY

Wood (Xylem)

Very hard, heavy and strong, the usually straight-grained sugar maple has a narrow white "red-tinged" sapwood with a uniformly light reddish-brown heartwood. Growth rings are fairly distinct, marked by a narrow darker line of denser fibrous tissue. Throughout the growth rings are small evenly distributed usually solitary pores. Classified as a diffuse porous wood, the xylem of sugar maple is composed of fibers, vessels and ray cells. The fibers average 20-25 μm in diameter and approximately 0.8 mm in length. Moderately thin to thick-walled, the fiber cell walls average 2-3 μm. There are 40-80 vessels per square millimeter, occurring as solitary vessels or in multiples of two or more. The vessel elements exhibit little variation in size throughout the growth rings. The largest vessels average 75-80 μm in diameter and between 0.4 and 0.5 mm in length. The wood rays

of the sugar maple are unstoried, essentially homogeneous and of two widths. The broad rays, visible to the naked eye, are separated by several narrow rays and appear on the tangential surface as short, crowded lines. These large, broad rays are usually 5-7 seriate and up to 0.8 mm in height. The narrow rays are principally uniseriate and less than 0.2 mm in height.

Bark (Phloem)

The bark on young trees is relatively smooth, firm and gray colored and becomes rougher and darker as the tree ages. The older, dark grayish-brown bark, generally hard and firm, develops deep furrows and tends to form long shaggy strips. Comparatively narrow, the total thickness of the bark of a young tree of approximately 6-10 inch diameter, is about 0.2-0.3 inch, half of which is inner bark, while an old tree has a bark thickness of up to 1 inch (1). Besley (10) estimated bark to make up 13% of the rough tree weight in sugar maple. This appears to be approximately 50% inner bark and 50% outer bark in older or mature trees. Figure 9 illustrates a cross section of sugar maple wood and bark with limited development of the periderm.

Anatomical Structure of Young Bark

At the outer surface, the bark of the young sugar maple is composed of a layer of epidermal cells, a periderm zone consisting of 4-5 layers of thin-walled phellem (cork) a phellogen layer, and a few layers of phelloderm. See Chang's (1) general description of bark (Fig. 1) in the section on Tree Growth and Bark Development. The cortex cells next to the periderm are small, collenchymalike and regularly aligned. Closer to the primary phloem, these cells increase in size, become more parenchymatous and loose in arrangement and often intermingle with the phloem tissues. Aligned in a circle around the axis, the primary phloem fibers appear in isolated groups. Between these groups sclereids form until a

complete cylinder of sclerenchyma tissue is formed as the tree grows older. Except for the lack of sclerenchyma cells in very young bark, the inner bark (secondary phloem) has the same tissue arrangement of broad phloem rays, sieve tubes and tangential layers of parenchyma as that of the mature bark.

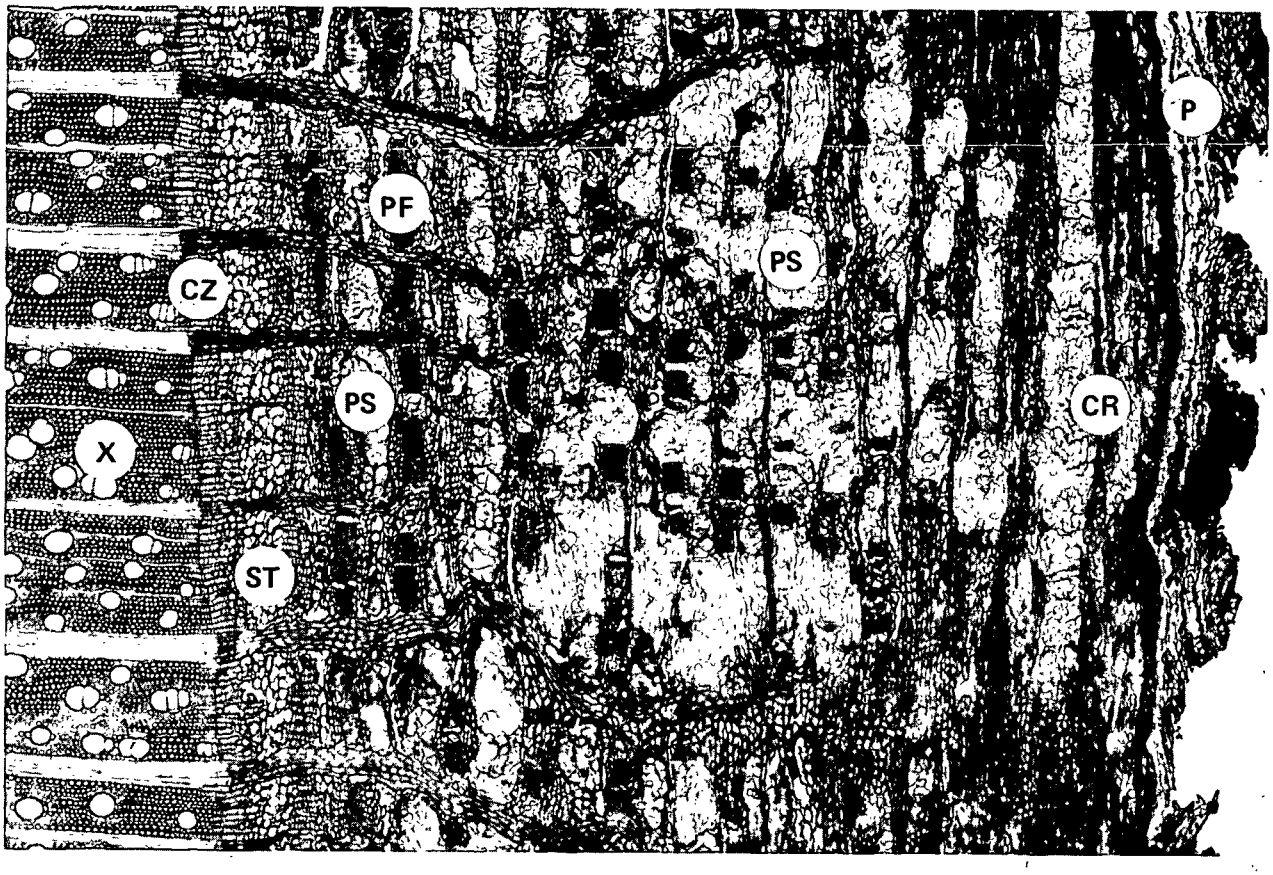


Figure 9. Cross Section of Acer saccharum with (Left to Right) Xylem (X), Cambium Zone (CZ), Inner Bark, Cortical Region (CR) and Periderm (P). The Secondary Phloem is Composed of Phloem Rays, Alternate Bands of Sieve Tubes (ST), Phloem Parenchyma, and Sclerenchyma. The Sieve Tubes Close to the Cambium Have Retained Their Fully Developed Shape and Size. The Sclerenchyma are of Two Types, Sclereids (PS) and Phloem Fibers (PF). Magnification — 50X

Anatomical Structure of Mature Bark

Broad and continuously developing, the periderm of the mature bark of sugar maple is composed of alternate layers of thin-walled suberized phellem and thick-walled peridermal (transformed phelloderm) cells, a layer of phellogen and 2-4 layers of phelloderm. As the first band of periderm retains its position outside the cortical region until middle age, the shaggy appearance of the outer bark or rhytidome appears quite late.

Persisting until middle age, the cortical region represents a proportionally narrow zone of the entire bark. This region usually consists of somewhat "lignified" cortex cells with abundant cell contents, cortical sclerenchyma, remains of primary phloem fibers and some mingling of secondary phloem tissues.

Phloem rays and alternate bands of sieve tubes, phloem parenchyma and sclerenchyma cells compose the inner bark (secondary phloem) of mature sugar maple. Homogeneous and principally 3 to 6 seriate, phloem rays are variable in width dilating toward the outer part of the inner bark and average more than 0.5 mm in height. Small rays prominent in the xylem are only evident in the cambium zone or in the inner bark (secondary phloem) immediately adjacent to the cambium. Rays are rather uniform in shape and size and ray cells generally retain their original shape and nature although some may become "sclerified" and merge into sclereid groups.

Bounded by the phloem rays and usually banded above and below by parenchyma cells, sieve tubes, in 2-3 tangential layers, retain their regular shape and size only in a zone close to the cambial area. Quite uniform in shape, sieve tube elements average 35-40 μm in tangential diameter but vary greatly

in length from 120-560 µm with ends varying from nearly horizontal to oblique. Beyond this zone, the thin-walled sieve tubes developed in previous years tend to collapse or become crushed.

Phloem parenchyma cells are aligned in tangential rows 2-4 layers wide throughout the inner bark. These cells average about 20-25 µm in tangential diameter and 200 µm in length. They may retain their original size and shape, expand, differentiate into fibers or be transformed into sclerotic cells.

Generally separated by 3-4 rows of parenchyma cells and crushed sieve tubes, tangential bands of sclerenchyma are characteristic of the inner bark of sugar maple. These thick-walled sclerenchyma bands are composed principally of sclerified ray and parenchyma cells and parenchyma that have elongated and developed "lignified" cell walls. Discontinuous tangential bands of fiber sclerenchyma cells appear at the middle portion of the inner bark (secondary phloem). These thick-walled fibers, polygonal in shape, have an average diameter of 14 µm and a length of approximately 0.7 mm.

SPECIFIC GRAVITY, EXTRACTIVES AND FIBROUS YIELD

As mentioned in the section on quaking aspen, basic information on such bark properties as specific gravity, level of extractives, fiber yield and the presence of such morphological elements as phloem fibers and sclereids are expected to be useful in determining the need and possible methods of separating and segregating wood/bark chip mixtures[9]. Whenever possible, data on bark have been compared with similar information on wood.

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[9]Throughout this report the term separation has been used to designate separation or detachment of wood from bark while segregation has been used to indicate removal of either the bark or wood fraction from wood/bark chip mixtures.

Specific Gravity

Specific gravity of bark and wood of sugar maple has been measured by a number of individuals. The data exhibit some variation, partly due to genetic and geographic differences and in part due to measurement techniques[10] and different ways of expressing the data. Table VII summarizes the information available and, whenever possible, information on bark is separated into inner and outer bark. Specific gravity is most often expressed as ovendry weight over green volume. It should be noted that several of the values in the above table are ovendry weights divided by ovendry volumes and the last set of values by Erickson (15) are green weight divided by green volume. Information expressed in terms of green weight divided by green volume is particularly useful when examining the possibilities of liquid flotation as a means of segregating wood/bark chip mixtures. Information in this report under the section Water Flotation Behavior compares the basic density (green weight divided by green volume) of sugar maple at several moisture contents.

An average specific gravity (ovendry weight/green volume) of approximately 0.59 appears appropriate for the wood of sugar maple. Our limited data do not show much of a difference between heartwood and sapwood although the heartwood is consistently higher in specific gravity.

The specific gravity of the total (inner + outer) bark of sugar maple appears somewhat lower than that of the wood, although not appreciably so. The inner bark appears to be higher in specific gravity than the wood while the outer bark is slightly lower. Overall values suggested for use in species comparison are 0.59 for wood, and 0.69, 0.49 and 0.54 for inner, outer and total bark.

[10] Increment core data, for example, tends to weight the center of the tree more heavily than the area near the cambium while disks and wedge-shaped samples provide representative values.

TABLE VII

SUGAR MAPLE SPECIFIC GRAVITY INFORMATION

(Ovendry weight/green volume)

Wood		Bark				
Average	Range	Inner	Outer	Total	Range	Reference & Remarks
0.562	0.504-0.600			0.505	0.446-0.602	Erickson (15)
0.608 (last-formed sapwood)		0.667	0.473	0.525		Lamb & Marden (14)
		0.67	0.56	0.53		Fournier & Goulet (12)
0.60						Besley (Canada) (10)
0.58						Besley (U.S.) (10)
0.56						Isenberg (9)
0.588	0.558-0.615			0.563	0.494-0.597	IPC determinations
0.618 (sapwood)		0.748	0.490			IPC 3212-2
0.628 (heartwood)						
0.614 (sapwood)		0.646	0.464	0.565		IPC 3212-27
0.644 (heartwood)						
		0.691	0.462	0.592		IPC 3212-28
				0.686[a]		Harkin & Rowe (17)
0.455[a]	0.407-0.511			0.821[a]		Erickson (15)
0.742[b]	0.670-0.819			0.955[b]		Erickson (15)

[a] Ovendry weight/ovendry volume.
[b] Green weight/green volume.

Extractives

Extractives in wood and bark are important because, when present in large amounts, they not only result in reduced yield of fibrous material but ultimately can be expected to result in paper machine "pitch problems." Recent needs to reduce total water use through closed white water systems are expected to accentuate problems in this area. No attempt has been made in this report to go beyond determining the total alcohol-benzene extractives. Such extractives information is expected to provide an appropriate indication regarding possible pitch problems when large amounts of bark are pulped. Further detailed examination of the types of extractives involved is recommended using specific bark sources if preliminary comparisons suggest pitch and yield problems may develop.

A range of levels of extractives from 0.31 to 5.2 has been reported for sugar maple (see Table VIII). For between species comparisons, an extractives level of 1.3% is suggested for the wood of sugar maple. The bark of sugar maple can be expected to have an extractives level of approximately 6%, which is considerably lower than the level in a number of other hardwoods.

TABLE VIII

SUGAR MAPLE ALCOHOL-BENZENE EXTRACTIVES

Type of Material	Extractives, %	Sources
Wood — clear sapwood	0.50	Levitin (38)
heartwood	0.31	
lightly stained wood	0.40	
heavily stained wood	0.54	
Wood	5.2	Isenberg (9)
Wood (sapwood)	1.31	Isenberg (9)
Wood (heartwood)	1.22	Isenberg (9)
Wood	1.25	Rydholm (22)
Bark	5.1	Harkin & Rowe (17)
Bark	7.14	IPC 3212-27
Bark	4.87	IPC 3212-28

Fibrous Yield

Increasing emphasis is being placed on pulping bark rather than debarking bolts or segregating wood/bark chip mixtures. Important to determining the usefulness of this approach with a particular species is determining the proportion of lignified cells that exist in the bark and that will survive normal cooking procedures. Also, it is important to determine what percentage of these cells will contribute in a favorable way to the resulting paper product.

There is a high percentage of sclereids in the inner bark of sugar maple and very little fibrous material. Sclereids are thick-walled, heavily lignified cells often found in clumps. They are of two types in sugar maple, short with very

thick walls or elongated with thick cell walls showing distinct pits. Counts made on macerated bark samples suggest that they make up about 15-18% of the bark total weight. When not fully cooked, as could occur in high-yield pulping, clumps of sclereids may cause so-called "fish-eyes" in certain grades (calendered) of paper. Levels of sclereids, as reported by Chang (1), for the inner bark of sugar maple are the highest of any of the species in this report. Our limited results suggest high levels of sclereids but located in more easily separated clumps than aspen.

In the inner bark of some species there occurs bands or groups of heavily lignified fibers. They are described in the literature as phloem fibers or sclerenchyma fibers. These fibers are the principal bark elements to survive chemical pulping and contribute to overall pulp yield and sheet strength. Chang (1) estimated that only 5.4% of the inner bark of sugar maple was composed of phloem fibers. As a further check on pulp yield and the nature of fibrous material produced from sugar maple, 20 to 30-gram samples were pulped using the IPC Standard Kraft Micropulping Procedure. For a complete description of this procedure see the section on Experimental Procedures. Table IX summarizes the results of this investigation.

Micropulping of sugar maple bark resulted in a 32 to 35% yield of solids. When screened, a high percentage (69-76%) of the material went through the 200-mesh screen while the coarse screens (60 and 100 mesh) retained most of the fibrous material. The "on 150 mesh" material was composed of primarily sieve tubes and parenchyma cells. The "through 200 mesh" material contained 50-60% sclereids and 30-40% crystalliferous parenchyma. Figure 10 illustrates the type of material retained on the 60 and 150-mesh screens.

TABLE IX

SUGAR MAPLE MICROPULPING INVESTIGATION

Data	Sample No. 3212-27	Sample No. 3212-28	Remarks
Yield, % solids	34.5	35.1	Third sample gave yield of 32.0%
Fraction			
on 60 mesh, %	5.6	3.3	Fraction contained primarily phloem fibers (90-95%) with small percentages of sclereids (< 5%), sieve tubes (< 5%) and parenchymatous cells (< 5%). The average fiber length of phloem fibers was 0.99 mm
on 100 mesh, %	6.4	4.2	Fraction contained large percentage of phloem fibers (60-70%) with smaller percentages of sieve tubes (10-20%), sclereids (5-10%), parenchymatous cells (5-10%) and a trace of crystalliferous parenchyma (< 1%). The average length of sieve tubes was 0.53 mm
on 150 mesh, %	10.0	7.5	Fraction contained large percentage of sieve tubes (40-50%) with smaller percentages of parenchymatous cells (20-30%), sclereids (10-20%), phloem fibers (10-20%) and crystalliferous parenchyma (< 5%)
on 200 mesh, %	9.4	9.2	Fraction contained large percentages of sclereids (40-50%) and parenchymatous cells (30-40%) with smaller percentages of sieve tubes (10-20%), crystalliferous parenchyma (5-10%) and phloem fibers (< 5%)
through 200 mesh, %	68.6	75.8	Fraction contained principally sclereids (50-60%) and crystalliferous parenchyma (30-40%) with a smaller percentage of parenchymatous cells (10-20%) and sieve tubes (< 5%)

Following the procedure established with aspen, i.e., considering that only the material located on the 60 and 100-mesh screens will end up in the paper furnish and have any influence on paper properties, it appears that, for every 100 grams of sugar maple bark pulped, about 34 grams of solids will be produced.

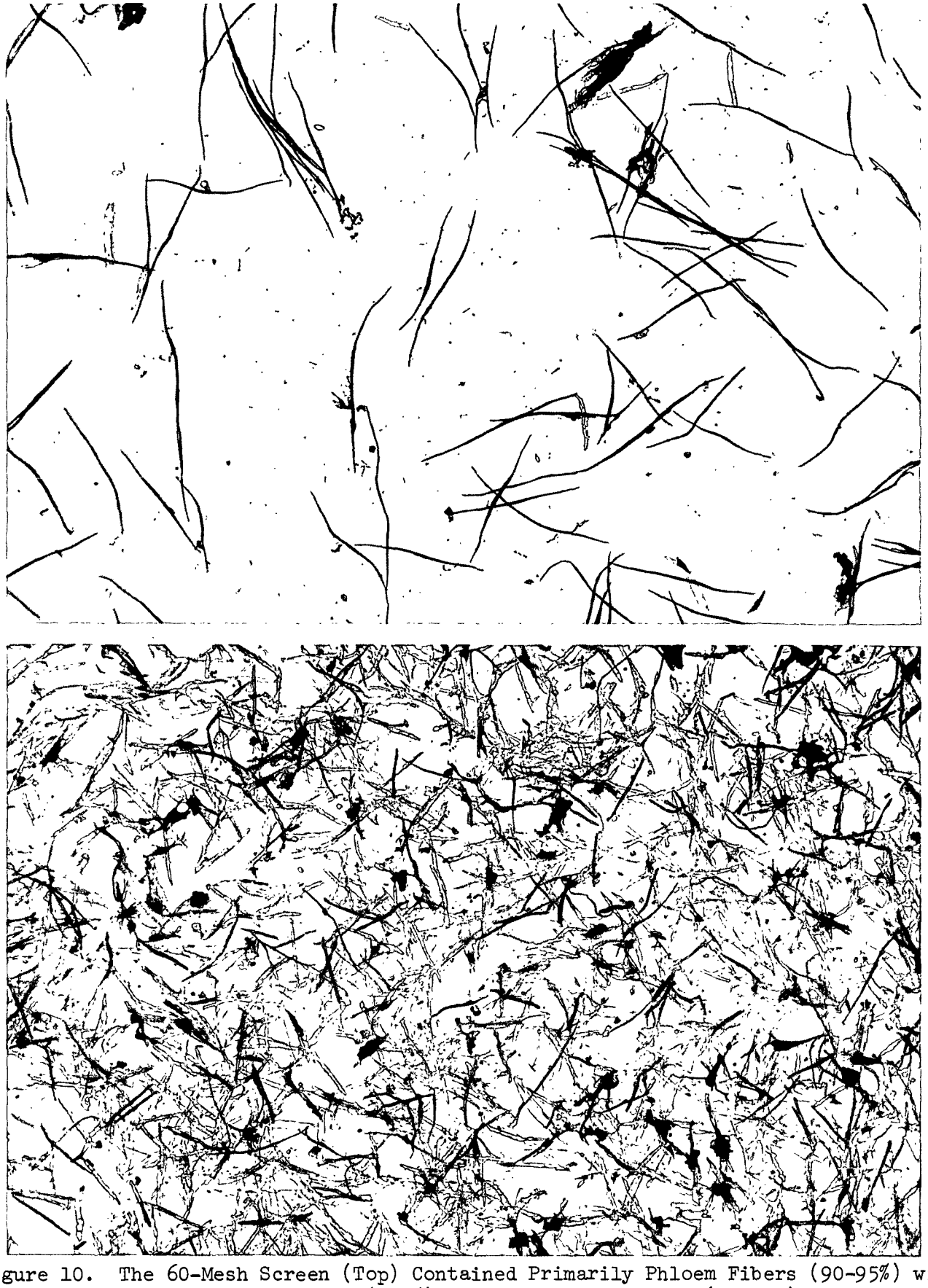

Figure 10. The 60-Mesh Screen (Top) Contained Primarily Phloem Fibers (90-95%) with Small Percentages of Sclereids (< 5%). The 150-Mesh Screen (Bottom) Contained a Large Percentage of Sieve Tubes (40-50%) with Approximately 10-20% Sclereids. Magnification — 35X

Because most of the elements that make up the solids are small in size, 100 grams of bark will produce only 3.2 grams of fiber, 0.5 gram of sieve tubes and parenchyma cells and only 0.2 gram of sclereids. The sclereids, even though they were present in high numbers in the bark, because they were small and ended up on the "on 200" and "through 200" mesh, are not expected to have any significant influence on paper properties.

WOOD/BARK ADHESION

Wood/bark adhesion differences have been suggested as one of the reasons for differences encountered in the ease of debarking pulpwood species. The same factors influencing debarking of pulpwood are expected to influence debarking of wood chips. The approach taken in the study has been to obtain growing season and dormant season information on (1) magnitude of wood/bark adhesion, (2) morphological structures associated with wood/bark adhesion, and (3) reasons for differences between species in adhesion.

Using the sampling and testing procedures described in the section on Experimental Procedures, shear parallel to the grain was measured for appropriately collected samples. Wood/bark adhesion in sugar maple was studied extensively in Project 2929 (Progress Report One) and the work was not repeated. A summary of the results of these earlier investigations is presented below.

Dormant season samples collected in April and August through October revealed a cambium zone of 4-5 cells in width and, when adhesion tests were made, failure consistently occurred in the inner bark, just outside the cambium zone and between the zone of phloem parenchyma cells and crushed sieve tubes and the bands of last-formed thick-walled sclerenchyma cells. During the growing season, wood/bark adhesion decreased and failure occurred either in the cambium zone or

3-4 cells outside the mature xylem cells of last year's growth or between the last-formed sclerenchyma cells and adjacent tangential bands of phloem parenchyma and crushed sieve tubes near the cambium. Figure 11 illustrates the changes in location of the zone of failure. Appendix Table XXVI gives the magnitude of wood/bark adhesion values involved and compares the values with a number of other species. Peeling season adhesion values for sugar maple averaged 5.8 kg/cm^2 while dormant season values averaged 10.1 kg/cm^2.

Dormant season wood/bark adhesion is related to inner bark strength and inner bark strength is in turn related to inner bark morphology. The presence of phloem fibers in the inner bark appears to be associated with high dormant season wood/bark adhesion. High numbers of sclereids seem to be associated with low dormant season wood/bark adhesion and low bark strength. Sugar maple with high numbers of inner bark sclereids and very few fibers has, as expected, low bark strength and medium to low dormant season wood/bark adhesion.

Separation (breaking the bond between bark and wood in a chip) is an important first step in the segregation (removal of bark particles from wood chips). Separation during the growing season, when wood/bark adhesion is low, can usually be accomplished by the action of the chipper. During the dormant season, adhesion is greater and separation by chipper action is less successful.

One of the most promising methods of effecting wood/bark separation on a difficult species like maple is through the use of chipper action. Arola (39) found that chipper action during the growing season gave better results than during the dormant season with less than 2% tight bark remaining on chips from 4-6 and 8-inch diameter bolts. Erickson (25) reported at least 96% separation

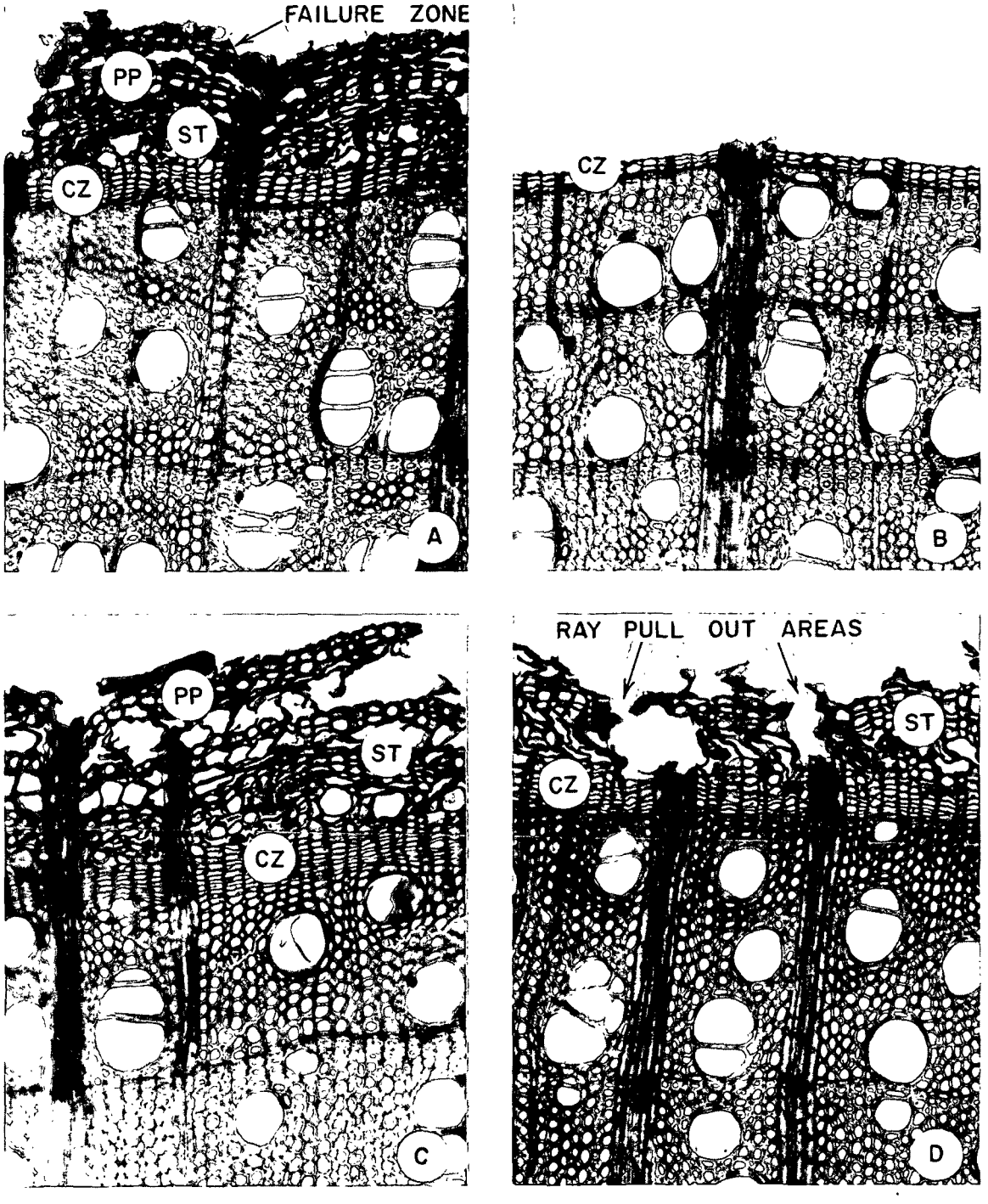

Figure 11. Illustrated are the Seasonal Changes in the Location of the Zone of Failure in Sugar Maple; A — May 18 Collection, Failure in Phloem Parenchyma and Sieve Tube Area (PP-ST) Just Outside the Cambium (CZ); B — June 1 Collection, Failure in Cambium Zone (CZ); C — June 29 Collection, Failure in Newly Formed Zone (CZ); D — August 10 Collection, Failure Again in the PP-ST Area with Failure Being Influenced by the "Pulling Out" of Phloem Rays

during chipping throughout the year. He also found better separation with winter-cut frozen wood over unfrozen bolts although more fines resulted and stated that storage in roundwood form for six months resulted in improved bark separation. IPC chipping studies performed on bolts collected in November resulted in less than 10% of the chips having bark attached.

Again, as mentioned before, a number of methods to reduce adhesion were investigated in Project 2929 work. They included several chemical, thermal and biological methods. The use of green kraft cooking liquor at a temperature of 200°F and a treatment time of 60 minutes gave reduced adhesion. The main disadvantage was the high temperatures and long treatment time required. Chemical treatments were also investigated by Haas and Kremers (27) and, in their work, dilute acids were effective in reducing adhesion. The principal disadvantage of this treatment was the length of time required to effect separation, the discoloration of the wood of some species and the ineffectiveness of the treatment on dry samples.

Pressure chamber treatments also looked promising with reduced treatment time needed when temperatures were in excess of 250°F. Moist storage of chips at temperatures that encourage fungus attack of the cambium zone resulted in greatly reduced wood/bark adhesion at storage times as short as 15-20 days. Another promising approach was the use of microwave heating to create high temperatures in the moist interior of the chips. There was a moderate reduction in wood/bark adhesion at treatment times as short as one minute.

BARK STRENGTH, TOUGHNESS AND REACTION TO HAMMERMILLING

Bark strength and toughness measurements are included as part of the characterization of bark because it was felt that, when these measurements are compared with the results obtained in wood/bark adhesion tests, with the difficulty encountered in conventional debarking and with bark morphology, the "why" of bark separation and segregation would eventually emerge.

Hammermilling has been widely used in bark utilization to prepare fractions for use as horticultural mulch, soil conditioners, and as additives to a number of types of products. Hammermilling has been suggested as one step in a wood/bark segregation procedure. A simulated hammermilling test was developed in an effort to relate the hammermilling of bark (and wood) to bark strength, toughness and morphology.

As discussed in the section on Experimental Procedures, bark strength measures shear parallel to the grain while bark toughness measures the energy required to rupture a thin specimen by a bending force perpendicular to the grain (parallel to the tree diameter). Table X summarizes the bark strength and bark toughness tests made on the wood and bark of sugar maple. Earlier investigations were made into bark strength as part of Project 2929 (Report Three). Included for comparison purposes are the bark strength values for a number of pulpwood species of interest (Appendix Table XXVII).

The bark strength of the inner bark of sugar maple is considerably less than that of aspen, although the toughness test values for both species were very similar. The low values for inner bark strength are probably related to the small amount of fiber in the inner bark and large numbers of sclereids.

TABLE X

SUMMARY OF STRENGTH AND TOUGHNESS MEASUREMENTS MADE ON WOOD AND BARK OF SUGAR MAPLE[a]

Material	Strength	Toughness
Sapwood	--	0.62
Inner bark	1.4	0.21
Outer bark	4.7	0.10

[a] Determinations made on two different trees.

Hammermilling results were also very similar to aspen, although sugar maple is a denser wood. Hammermilling, followed by screening, can be expected to result in only a moderate reduction in levels of bark. When the half-sized chips for the two trees investigated were hammermilled, and the material on the 14-mesh screen retained, the result was a 5% loss in wood and a 29% reduction in bark. A large amount of the bark removed was outer bark. Since there are large numbers of sclereids and little fiber in the inner bark, the improvement in chip quality through hammermilling would not be substantial. Summarized in Table XI are the results of the hammermilling tests run on sugar maple wood and bark. Figure 12 illustrates the effect of hammermilling on sugar maple wood and bark.

WATER FLOTATION BEHAVIOR

One possible method of segregating wood/bark chip mixtures is by water flotation procedures. Knowledge of the flotation characteristics of wood and bark is also expected to be important when certain types of chip washing procedures are employed. Earlier investigations into water flotation segregation (Project 2977) revealed that chip size, specific gravity, moisture content and rate of moisture uptake were factors in the flotation behavior of bark and wood chips.

Budget limitations do not permit examination of all the factors involved and, as a result, the influence of chip size has been eliminated from the variables considered.

TABLE XI

SUMMARY OF HAMMERMILLING TEST ON SUGAR MAPLE

Tree No.	Type Material	Fraction Retained on Standard Screen[a], % 5 Mesh	10 Mesh	14 Mesh	20 Mesh	28 Mesh	< 28 Mesh	Remarks
3212-27	Bark	39	25	10	5	6	15	High proportion (50-65%) of bark on 5, 10 & 14-mesh screens is inner bark; mostly outer bark on 20, 28 and < 28-mesh screens
	Heartwood	84	9	3	1	1	2	
	Sapwood	84	9	2	2	1	2	
3212-28	Bark	25	30	13	6	9	17	Approximately half of bark on 5, 10 & 14-mesh screens is inner bark; fines only has higher proportion of outer bark
	Heartwood	84	7	3	1	2	3	
	Sapwood	88	6	2	1	1	2	

[a]Standard soil screen sizes; 5 mesh has 5 wires per inch and an opening of 4.00 mm, 10 mesh has 10 wires per inch and an opening of 2.0 mm, 14 mesh has 14 wires per inch and an opening of 1.168 mm, 20 mesh has 20 wires per inch and an opening of 1.00 mm, and the 28-mesh screen has 28 wires per inch and an opening of 0.589 mm.

Two procedures were used to examine the water flotation behavior of wood and bark. One procedure involved measuring the density[11] (green weight divided by green volume) of simulated chips at a number of different moisture contents. The second technique involved measuring the rate of moisture uptake and sinking of wood and bark chips in what have been designated as "dwell time" studies.

[11]The term density is used in this report to indicate the weight of wood and bark samples and is expressed in the terms of green weight divided by green volume. This is in contrast to the term specific gravity, which also is an expression of the weight of a sample, but in this case it is in terms of dry weight divided by green volume.

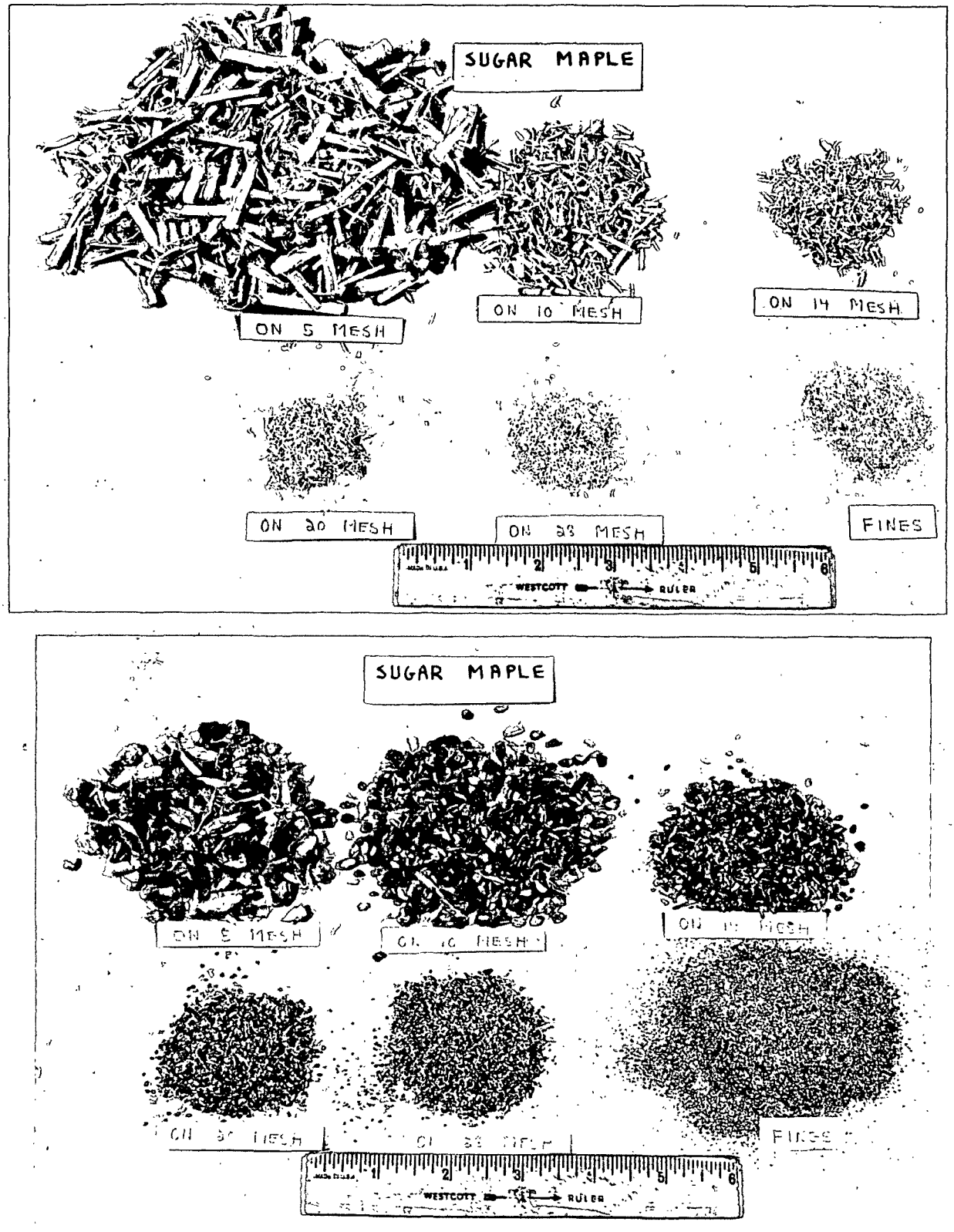

Figure 12. Illustrated is the Effect of Hammermilling on Sugar Maple Wood (Top) and Bark (Bottom)

Density Determinations

Simulated chips were used in determining the relationship between moisture content and density of bark and wood. Wood and bark from two sugar maple trees (IPC 3212-2 and 3212-27) were used in making the determinations. The moisture content of the chip samples was adjusted by equilibrating in small jars to which had been added appropriate amounts of water. The extremely accurate pycnometer method described in the Experimental Procedures was used in determining density. The wood samples used included both heartwood and sapwood and, in the preliminary plotting of the wood data, it became apparent that no density differences existed between the two types of wood. As a result, the data were handled as a single population. Bark samples used were "whole bark" samples, a combination of both inner and outer bark. Small chips of inner and outer bark were also tested. The outer bark tended to have a considerably lower density than the inner bark which is the reverse of the aspen inner and outer bark relationship.

Figure 13 illustrates the relationship that was found between moisture content and density. The linear relationship shown was obtained by fitting the least squares regression line through the data. The dashed lines are two standard deviations above and below the average values. The standard deviation of the regression line is considerably less than would have been obtained if conventional mill-run chips had been used for the water flotation studies, because the simulated chips were uniform in size and shape, had a uniform level of moisture and were relatively free of knots, reaction wood, etc. Water segregation is believed to be possible when one fraction has a density of less than one and the other greater than one at a specific moisture content.

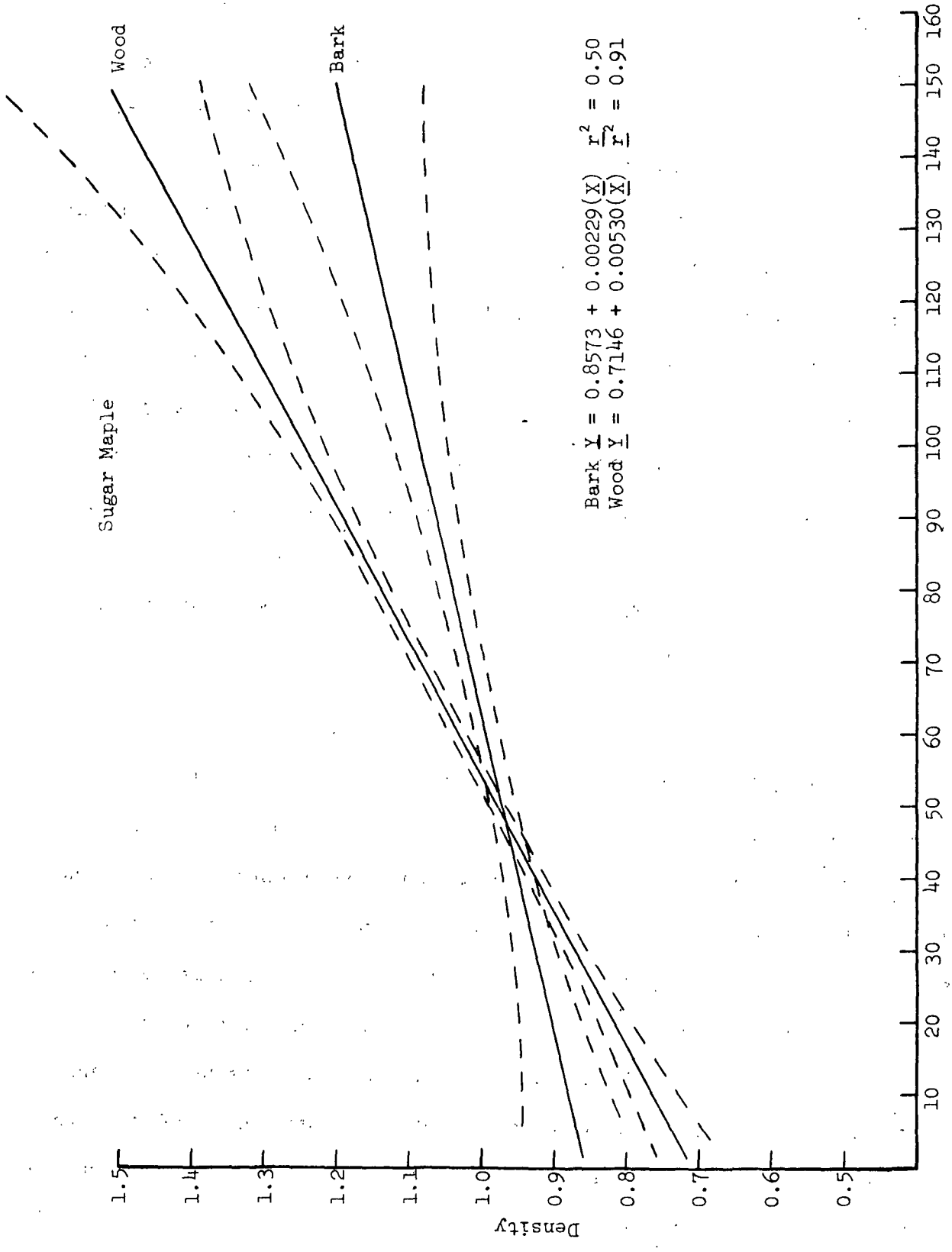

Figure 13. Illustrated is the Relationship Between Basic Density and Moisture Content for Sugar Maple. The Dashed Lines are Two Standard Deviations Above and Below the Mean

The data indicate that separation through water flotation would be difficult to achieve. The wood and bark fractions are close in basic density at any moisture content of less than 100%. At moisture contents above 100% both fractions have a density greater than that of water and could be expected to sink. Robins (36) also reported unsatisfactory results with sugar maple using the Cartesian Diver principle and concluded that good segregation in water was not possible. The results of Project 2977 work with conventional-shaped sugar maple chips further indicate that bark chips respond to flotation in a manner similar to wood chips. Battering the chips to separate inner from outer bark, agitating the chips in water, air drying and refloating for 24 hours gave somewhat improved results.

As discussed earlier in the section on aspen, with conventional chips not all bark chips are total bark (inner + outer bark). Some are all outer bark, some are mostly inner bark and some have wood attached. Also, the moisture content of outer bark is often less than that of inner bark when conventional chips are used. Air entrapment in bark can reduce bark specific gravity and the presence of reaction wood and stain can greatly increase wood specific gravity to the point that a certain part of the total sample will not behave as expected.

Dwell Time Investigations

An investigation of dwell time involves nothing more than taking wood and bark chips at some standard moisture content, placing them on a water surface and observing the time it takes the material to pick up enough water to sink. Information on dwell time is useful because moisture uptake rate could have a considerable influence on the success of a segregation procedure (or chip washing procedure) and would provide information on the rate at which segregation could be expected.

Half-sized simulated chips (1 x 0.3 x 0.2 inches) were used in the dwell time tests. Prior to testing, the samples were equilibrated in 50% RH and had a moisture content of approximately 20% (ovendry basis). Table XII summarizes the results for sugar maple. As was expected from the basic density results, both the bark and the wood of sugar maple tended to float, probably due to both a similarity in density and a similarity (very slow) in moisture uptake. In all cases, as shown in Table XII, at least 80% of both the bark and wood was floating after four hours.

DATA INTERPRETATION

Segregation of sugar maple wood/bark chip mixtures has turned out to be difficult to accomplish. Chipper action works well in separation of the bark from the wood, apparently because of low bark strength and low wood/bark adhesion due in turn to the lack of bark fibers. Similarities of the bark and wood in specific gravity and moisture uptake make segregation through water flotation and other techniques difficult to achieve. Both dwell time investigations and density determinations substantiate these observations.

Since the inner bark of sugar maple has many sclereids and few fibers, removal of the bark seems desirable in many instances. One method that shows promise is to screen and concentrate the bark in the small-sized chip fractions, hammermill or compression debark (25-26) the selected fractions and then screen the hammermilled or compression debarked fractions to remove bark fines.

Another approach that may be feasible is to pulp bark. Maple bark, after pulping, is surprisingly low in sclereids compared to the amounts found in whole bark. It appears that sclereids are not found in clumps to the extent that they are in aspen and pass through the fine mesh screens and are lost. However, with

the small amount of fiber in sugar maple, 100 grams of bark will produce only about 4 grams of usable material.

TABLE XII

SUMMARY OF DWELL TIME RESULTS FOR SUGAR MAPLE[a]

Sample No.	Time Interval, min	Sinkers, %	Floaters, %
IPC 3212-27 Sapwood	after 5	0	100
	15	0	100
	60	0	100
	240	7.2	92.8
IPC 3212-27 Heartwood	after 5	0	100
	15	0	100
	60	0	100
	240	8.5	91.5
IPC 3212-27 Bark	after 5	0	100
	15	0	100
	60	0	100
	240	5.8	94.2
IPC 3212-28 Sapwood	after 5	0	100
	15	0	100
	60	0	100
	240	14.8	85.2
IPC 3212-28 Heartwood	after 5	0	100
	15	0	100
	60	5.3	94.7
	240	18.3	81.7
IPC 3212-28 Bark	after 5	0	100
	15	0	100
	60	0	100
	240	0	100

[a]Starting moisture content 20%.

RELATED LITERATURE

During the process of reviewing and assembling the information on the bark and wood of sugar maple, a number of papers containing related information were reviewed. These papers are described in the paragraphs that follow.

The paper by Erickson (15) cited in the information on specific gravity of sugar maple also contains information on moisture content of bark and wood. Also containing information on moisture content and amounts of bark as a percentage of rough tree weight is the paper by Besley (10).

An additional reference on seasonal variation in wood/bark adhesion is: Wilcox, et al. (33).

There were several papers dealing with separation and segregation of chip/bark mixtures and compression debarking. They include: (1) Erickson, J. R. Bark-chip segregation: a key to whole-tree utilization (40) and (2) Plahutnik, F., Jr. Improvement of pulpwood yield. Application of the Cartesian-Diver principle to wood-bark chip mixtures (35).

BARK AND WOOD PROPERTIES OF WHITE BIRCH (Betula papyrifera Marsh.)

SILVICULTURAL CHARACTERISTICS AND GEOGRAPHIC RANGE

One of the three commercially most important of the birches, white birch, a hardwood and a cold climate species, has a transcontinental range extending from northeastern United States through most of Canada to Alaska, reaching northward almost to the limit of tree growth. In the United States, although white birch is most abundant in the northern New England area, it is common in the Lake States and New York and is also found in scattered localities of other northern states and on a few high mountains in West Virginia and North Carolina.

Growth and development of white birch, which can reach 50 to 70 feet in height, 1 to 2 feet in diameter, are dependent on climate and soil conditions. There is a wide tolerance in pattern and amount of precipitation, but in general white birch grows best with short, cool summers where the average July temperature does not exceed 70 degrees and cold winters with ground snow cover for long periods. Well-drained sandy loam soils encourage the best development, although shallow stony soils and even bog and peat soils are common. Podzol soils, a result of relatively cool climate, high rainfall, and good drainage, are the usual sites of white birch.

WOOD AND BARK MORPHOLOGY

Wood (Xylem)

The wood of white birch varies in color from a whitish-yellow or light reddish-brown sapwood to dark or reddish-brown heartwood. Growth rings are frequently not distinct and pores appear as whitish dots to the naked eye. Straight-grained and classified as a diffuse porous wood, the xylem is composed

of fibers, longitudinal parenchyma cells, vessels and ray cells. As viewed on cross sections, the vessels are solitary or in clusters of 3-6. The largest vessels are 60-160 μm in diameter and there are 50-100 vessels per square millimeter. The rays are unstoried, 1-5 seriate and homogeneous. Fibers average 25-30 μm in diameter and 1.5-2.0 mm in length and have a cell wall thickness of 3-4 μm.

Bark (Phloem)

Dark brown at first, the bark of white birch becomes chalky to creamy white, separating into thin papery layers. It is generally smooth along most of the trunk with local areas of peeling, and especially in older trees, becomes nearly black and deeply fissured at the basal end of the trunk. Cross-sectioned, the regular layers of the periderm are easily discernible and the inner bark (secondary phloem) and cortical regions are light yellowish-brown in color with conspicuous sclereid groups. The percentages of inner and outer bark are typically 75 and 25% by weight, respectively, for pulpwood-sized trees (6-10 inches dbh). Figure 14 illustrates some of the described elements that comprise the wood and bark of white birch.

Anatomical Structure of Young Bark

The periderm in the outer bark consists of continuously developed and compactly arranged phellem or cork cells of rather uniform size, shape and cell wall thickness and large cell cavities. One to two layers of phelloderm usually occur on the inner side of the phellogen. Lenticel openings may extend through the periderm deep into the cortical region. Abundant sclerotic cortical cells appear in the cortex which consists of a few layers of collenchymalike cells and ordinary cortex cells aligned more or less in tangential rows. The cortex cells are of a parenchymous nature and contain plastids, tanniferous substances and often

crystals. Except for the lack of sclereids, the secondary phloem appears in the young bark as in the mature.

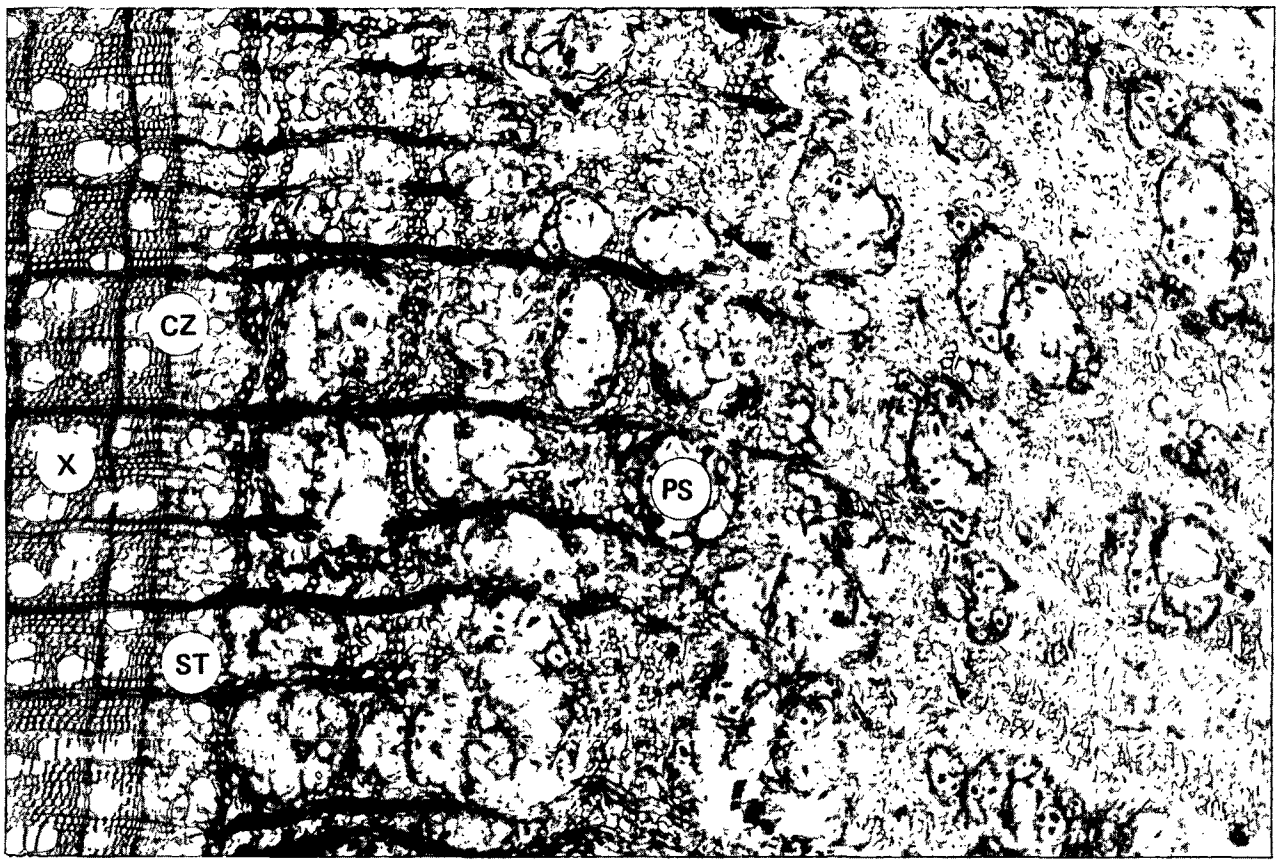

Figure 14. Cross Section of Betula papyrifera with (Left to Right) Xylem (X) Cambium Zone (CZ), Newly Formed and Uncrushed Sieve Tubes (ST) and Inner Bark. The Sclerenchyma Present in White Birch are Thick-Walled Sclereid Cells (PS). There are no Phloem Fibers Present in White Birch. Magnification — 50X

Anatomical Structure of Mature Bark

The periderm of white birch is made up of two different forms of phellem cells. The radial dimensions of one form show distinct striations. Although the tangential diameter and height of both cell types are about the same, the radial diameter of the narrow cell form is about 5 μm and the broad form, 12 μm and up.

The seasonal growth of the trunk corresponds more or less to the alternate growth of the phellem cells, and the boundary between the two types can account for the "peeling" of the bark or periderm.

The cortical region persists up to the middle age of white birch trees. With abundant intercellular spaces and increased sporadic sclereids, the parenchymatous cortex cells are like those of the young tree.

The inner bark (secondary phloem) of the mature paper birch is made up of sieve tubes, parenchyma and ray cells and thick-walled sclerenchyma cells or sclereids arranged in large groups. There are no fibers in the inner bark of white birch. Sieve tubes, aligned in 1-3 tangential layers, are polygonal in shape and vary in diameter from 20-60 μm depending on direction of measurement (radial or tangential) and in length from 520-1250 μm. Patterns of sieve tube groups are formed by the distribution of the phloem ray cells. Phloem parenchyma cells, are more or less circular in cross section with an average diameter of 20 μm and height of 100-150 μm. These reticular cells are distributed throughout the secondary phloem and some are transformed to form large groups of sclereids with adjacent sclerified ray cells. Phloem rays are homogeneous and generally 3-seriate. Conspicuously broader than in the xylem, the rays average 15-20 cells and approximately 300 μm in height near the cambium. Some ray cells become sclerified, having developed a lignified secondary wall. These transformed ray and parenchyma cells form the sclerenchyma cells or sclereid groups. Very thick-walled and irregular in size and shape, 20-30 cells form a large sclereid-group. The groups of sclereid cells generally are separated from the cambium by 5-6 rows of sieve tubes.

SPECIFIC GRAVITY, EXTRACTIVES AND FIBROUS YIELD

As discussed in the sections on quaking aspen and sugar maple, basic information on such bark properties as specific gravity, level of extractives, fiber yield and the presence of such morphological elements as phloem fibers and sclereids are expected to be useful in determining the need and possible methods of separating and segregating wood/bark chip mixtures[12]. Whenever possible, data on bark have been compared with similar information on wood.

Specific Gravity

Specific gravity of bark and wood has been measured by a number of individuals. The variation exhibited by the data can be attributed to genetic and geographic differences and also to measurement techniques[13] and different ways of expressing the data. Table XIII summarizes the information available and, whenever possible, information on bark is separated into inner and outer bark. Specific gravity is most often expressed as ovendry weight over green volume. Information expressed in terms of green weight over green volume is particularly useful when examining the possibilities of liquid flotation as a means of segregating wood/bark chip mixtures. Information in this report under the section Water Flotation Behavior compares the basic density (green weight divided by green volume) of white birch at several moisture contents.

An average specific gravity (ovendry weight/green volume) of approximately 0.49 appears appropriate for the wood of white birch. Our limited data show the sapwood to be higher in specific gravity than the heartwood although more trees would have to be sampled to determine whether this is a meaningful trend.

[12]Throughout this report the term separation has been used to designate separation or detachment of wood from bark while segregation has been used to indicate removal of either the bark or wood fraction from wood/bark chip mixtures.

[13]Increment core data, for example, tends to weight the center of the tree more heavily than the area near the cambium while disks and wedge-shaped samples provide representative values.

TABLE XIII

WHITE BIRCH SPECIFIC GRAVITY INFORMATION

(Ovendry weight/green volume)

Wood		Bark				
Average	Range	Inner	Outer	Total	Range	Reference & Remarks
0.507		0.515	0.522	0.516		Lamb & Marden (14)
		0.52	0.52	0.52		Fournier & Goulet (12)
0.50	0.47-0.59					Besley (Canada) (10)
0.50						Besley (U.S.) (10)
0.48						Isenberg (9)
0.517	0.484-0.543			0.542	0.512-0.559	IPC determinations
0.504 (sapwood)		0.582	0.563	0.586		IPC 3212-19
0.437 (heartwood)						
0.458 (sapwood)		0.666	0.570	0.639		IPC 3212-20
0.448 (heartwood)						
				0.687[a]		Harkin & Rowe (17)

[a] Ovendry weight/ovendry volume.

The specific gravity of the total (inner + outer) bark of white birch appears somewhat higher than that of the wood, although not appreciably so. The inner and outer bark are close in specific gravity. Overall values suggested for use in species comparisons are 0.49 for wood, and 0.57, 0.54 and 0.56 for inner, outer and total bark.

Extractives

Extractives in wood and bark are important because, when present in large amounts, they not only result in reduced yield of fibrous material but ultimately can be expected to result in paper machine "pitch problems." Recent needs to reduce total water use through closed white water systems are expected to accentuate problems in this area. No attempt has been made in this report to go beyond determining the total alcohol-benzene extractives. Such extractives information is expected to provide an appropriate indication regarding possible pitch problems when large amounts of bark are pulped. Further detailed examination

of the types of extractives involved is recommended using specific bark sources if preliminary comparisons suggest pitch and yield problems may develop.

Table XIV summarizes available information on extractives levels in wood and bark of white birch and includes two white birch (3212-19 and 3212-20) sampled as part of this project. White birchwood is low in extractives and a level of 4% is suggested for use in species comparisons. The bark of white birch has a considerably higher level of extractives and the average level suggested for bark is 17%. This level of extractives, although fairly high, is not expected to be a serious problem except in those instances where high percentages of bark have been concentrated in a particular chip fraction by screening or other mechanical techniques.

TABLE XIV

WHITE BIRCH ALCOHOL-BENZENE EXTRACTIVES

Type of Material	Extractives, %	Sources
Wood	2.8	Isenberg (9)
Wood (sapwood	3.3	Isenberg (9)
Wood (heartwood)	6.4	Isenberg (9)
Wood	2.8-6.4	Rydholm (22)
Bark	19.9	Harkin & Rowe (17)
Bark	17.5	IPC 3212-19
Bark	12.4	IPC 3212-20

Fibrous Yield

Increasing emphasis is being placed on pulping bark rather than debarking bolts or segregating wood/bark chip mixtures. Important to determining the usefulness of this approach with a particular species is determining the proportion of lignified cells that exist in the bark and that will survive normal cooking procedures. Also, it is important to determine what percentage of these cells will contribute in a favorable way to the resulting paper product.

Sclereids are short, thick-walled, heavily lignified cells. When not fully cooked, as could occur in high-yield pulping, clumps of sclereids may cause so-called "fish-eyes" in certain grades (calendered) of paper. Estimates made on IPC macerated bark samples suggest that sclereids make up 18-23% of the total bark weight. According to Chang, 28.4% of the tissue elements in the inner bark of white birch are sclereids. These values seem in good agreement when one considers the inner bark is the zone of highest sclereid content.

In the inner bark of some species there occurs bands of heavily lignified fibers described in the literature as phloem fibers or sclerenchyma fibers. These fibers are the principal bark elements to survive chemical pulping and contribute to overall pulp yield and sheet strength. Chang (1) felt these fibers were absent in the inner bark of white birch. As a further check on pulp yield and the nature of fibrous material produced from white birch, 20 to 30-gram samples were pulped using the IPC Standard Kraft Micropulping Procedure. For a complete description of the procedure see the section on Experimental Procedures. Table XV summarizes the results of this investigation.

Micropulping white birch resulted in a 32 to 38% yield of solids. When screened, most (85-89%) of the material went through the 200-mesh screen. Retained on the coarse screens (60 and 100-mesh) were primarily sieve tubes. The "on 150 mesh" and "on 200 mesh" material was mainly sclereids. The "through 200 mesh" contained 60-70% sclereids and 30-40% parenchymatous cells. Figure 15 illustrates the type of material retained on the 60 and 150-mesh screens.

Following the procedure established for aspen and maple, i.e., considering that only the material located on the 60 and 100-mesh screens will end up in the paper furnish and have any influence on paper properties, it appears that for every 100 grams of white birch bark pulped about 35 grams of solids will

be produced. Most of the usable material (2 grams) will be sieve tubes and a good share of the rest will be material (sclereids and parenchymatous cells) that will be lost in cleaning operations. The sieve tubes cannot be expected to add to the paper properties but would act more as a filler material. Chase, et al. (23) after pulping gray birch puckerbrush bark, reported a screened yield of 40.5% but also stated that much of the material was uncooked and gelatinous with little fibrous nature.

TABLE XV

WHITE BIRCH MICROPULPING INVESTIGATIONS

Data	Sample No. 3212-19	Sample No. 3212-20	Remarks
Yield, % solids	33.5	38.0	Two other samples gave yields of 31.9 and 31.8
Fraction			
on 60 mesh, %	2.4	1.3	Fraction contained a large percentage of sieve tubes (70-80%) with smaller percentage of sclereids (20-30%) and parenchymatous cells (< 5%)
on 100 mesh, %	5.8	4.3	Fraction contained large percentage of sieve tubes (50-60%) with smaller percentages of sclereids (20-30%) and parenchymatous cells (10-20%). The average arithmetic length of sieve tubes was 1.06 mm
on 150 mesh, %	5.2	3.1	Fraction contained a large percentage of sclereids (50-60%) with smaller percentages of parenchymatous cells (20-30%) and sieve tubes (10-20%)
on 200 mesh, %	2.0	2.3	Fraction consisted principally of sclereids (70-80%) with a relatively smaller percentage of parenchymatous cells (20-30%) and sieve tubes (< 5%)
through 200 mesh, %	84.6	89.0	Fraction contained primarily sclereids (60-70%) and parenchymatous cells (30-40%)

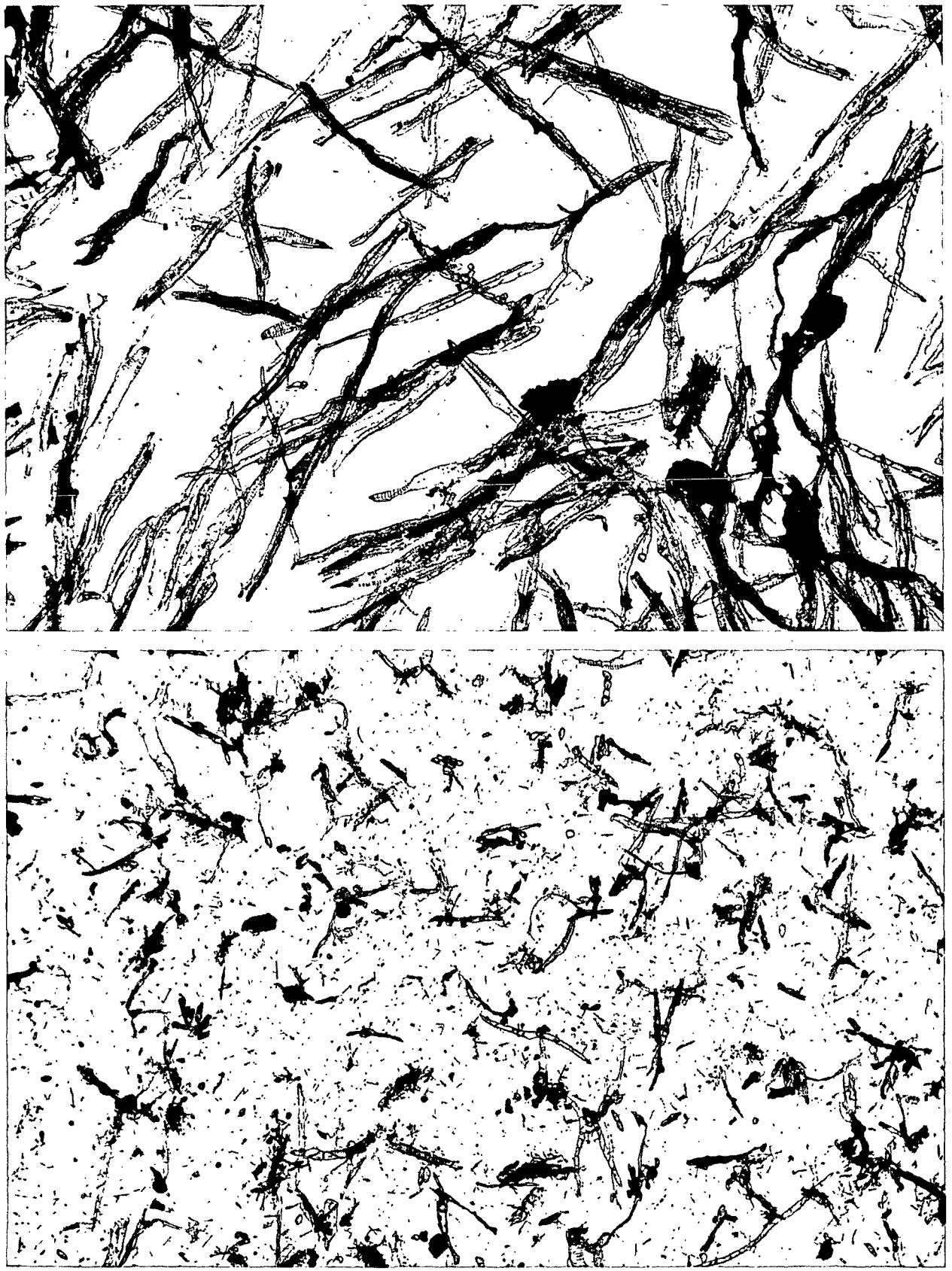

Figure 15. The 60-Mesh Screen (Top) Contained Primarily Sieve Tubes (70-80%) with Smaller Percentages of Sclereids (20-30%). The 150-Mesh Screen (Bottom) Contained a Large Percentage of Sclereids (50-60%) with Smaller Percentages of Parenchymatous Cells (20-30%) and Sieve Tubes (10-20%). Magnification — 35X

WOOD/BARK ADHESION

Wood/bark adhesion differences have been suggested as one of the reasons for differences encountered in the ease of debarking pulpwood species. The same factors influencing debarking of pulpwood are expected to influence debarking of wood chips. The approach taken in the study has been to obtain growing season and dormant season information on (1) magnitude of wood/bark adhesion, (2) morphological structures associated with wood/bark adhesion and (3) reasons for differences between species in adhesion.

Using the sampling and testing procedures described in the section on Experimental Procedures, shear parallel to the grain was measured for appropriately collected samples. Wood/bark adhesion in white birch was studied extensively in Project 2929 (Progress Report One) and the work was not repeated but a summary of the results of earlier investigations is presented below.

Dormant season samples collected in March, April, August, and September revealed a cambium zone 3 to 6 cells in width and, when adhesion tests were made, failure quite consistently occurred in the inner bark in an irregular break starting on one edge in the sieve tubes near the cambium. However, during early dormancy (August), the failure occurred in the cambium zone and moved into the inner bark in September. During the growing season, wood/bark adhesion decreased and failure occurred either in the cambium zone or in the last-formed nonlignified xylem cells. Figure 16 illustrates the changes in location of the zone of failure and Appendix Table XXVI gives the magnitude of wood/bark adhesion values involved. Included for comparison purposes are the results of wood/bark adhesion tests run on several other tree species. Peeling season adhesion values for white birch averaged 5.1 kg/cm^2 while dormant season values averaged 12.0 kg/cm^2.

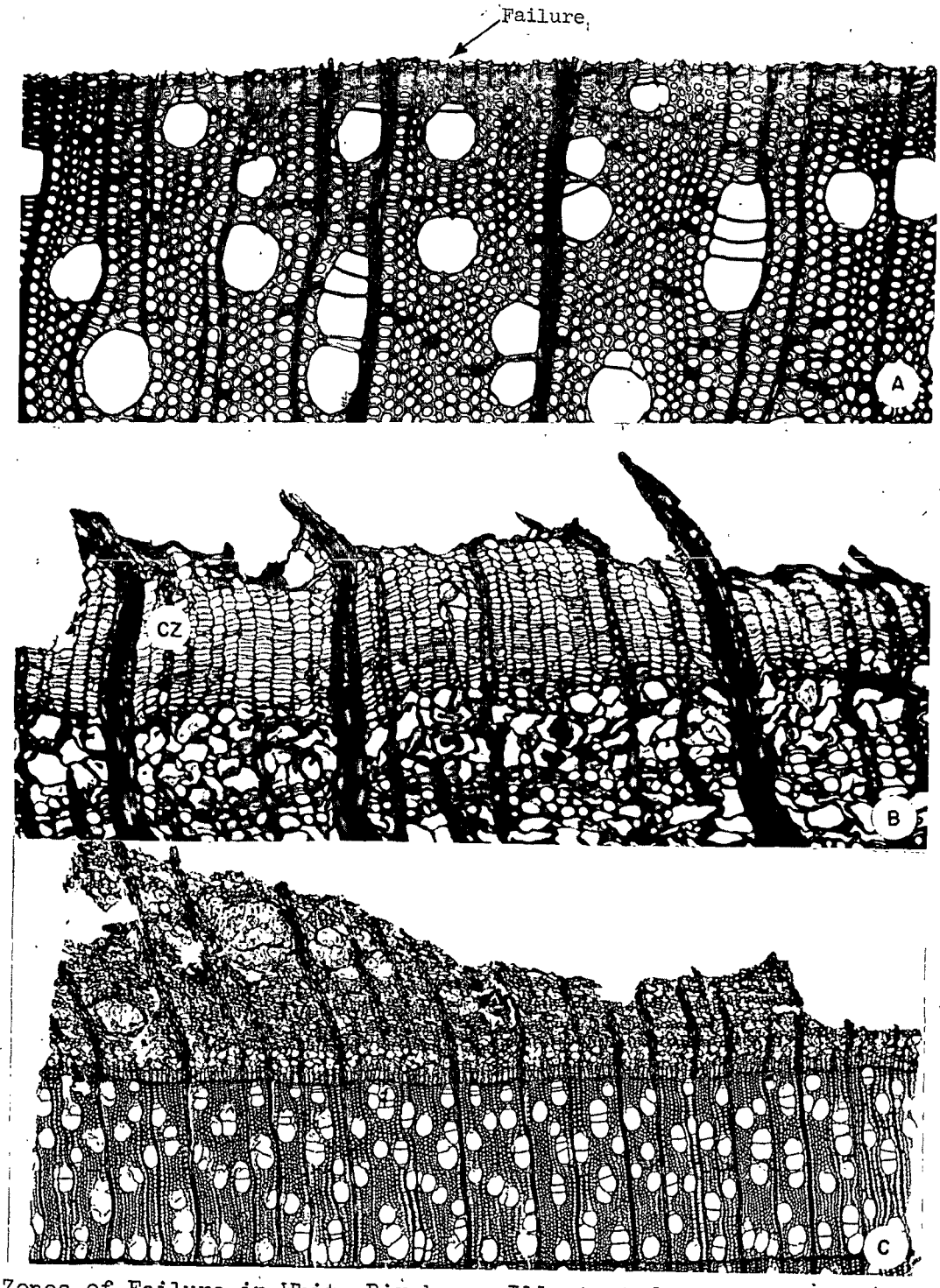

Figure 16. Zones of Failure in White Birch are Illustrated for: A — May 4 Collection, Failure Along Newly Active Cambium; B — June 1 Collection, Failure Just Outside Very Active Cambium Zone (CZ) in Newly Formed Nonlignified Xylem, Ray Stubs Prominent; C — September 14 Collection, Failure Started in Inner Bark Area Near Cambium (Right) and Progressed Diagonally Across Older Sieve Tube Areas of Inner Bark. The Wood is in the Lower Area of Cross Sections A and C and in the Upper Area in Cross Section B

As a result of measurement data taken on white birch and the other species included in Appendix Table XXVI, it became clear that dormant season wood/bark adhesion was related to inner bark strength and inner bark strength is in turn related to inner bark morphology. The presence of phloem fibers in the inner bark appears to be associated with high dormant season wood/bark adhesion. High numbers of sclereids seem to be associated with low dormant season wood/bark adhesion and low bark strength.

Separation (breaking the bond between bark and wood in a chip) is an important first step in segregation (removal of bark particles from wood chips). Separation during the growing season, when wood/bark adhesion is low, can usually be accomplished by the action of the chipper. During the dormant season, adhesion is greater and separation by chipper action is less successful.

The effect of chipper action on separation of dormant white birchwood and bark was studied using the Institute's 41-inch, 4-knife Carthage Chipper[14]. Several white birch pulpwood bolts (5-7 inches in diameter) were collected in November and chipped 3-4 days after collection. Separation of bark and wood was quite good although not as satisfactory as with aspen. Approximately 25% of the bark chips had wood attached.

As discussed earlier, a number of methods to reduce adhesion were investigated in Project 2929 work. They included several chemical, thermal and biological methods. The use of green kraft cooking liquor at a temperature of 200°F and a treatment time of 60 minutes gave reduced adhesion. The main disadvantage was the high temperatures and long treatment time required. Chemical treatments were also

[14]Chipper runs reported as part of Project 2929 work.

investigated by Haas and Kremers (27) and, in their work, dilute acids were effective in reducing adhesion. The principal disadvantage of this treatment was the length of time required to effect separation, the discoloration of the wood of some species and the ineffectiveness of the treatment on dry samples.

Pressure chamber treatments also looked promising with reduced treatment time needed when temperatures were in excess of 250°F. Moist storage of chips at temperatures that encourage fungus attack of the cambium zone resulted in greatly reduced wood/bark adhesion at storage times as short as 15-20 days. Another promising approach was the use of microwave heating to create high temperatures in the moist interior of the chips. There was a moderate reduction in wood/bark adhesion at treatment times as short as one minute.

BARK STRENGTH, TOUGHNESS AND REACTION TO HAMMERMILLING

Bark strength and toughness measurements are included as part of the characterization of bark because it was felt that, when these measurements are compared with the results obtained in wood/bark adhesion tests, with the difficulty encountered in conventional debarking and with bark morphology, the "why" of bark separation and segregation would eventually emerge.

Hammermilling has been widely used in bark utilization to prepare fractions for use as horticultural mulch, soil conditioners, and as additives to a number of different types of products. Hammermilling has been suggested as one step in a wood/bark segregation procedure. A simulated hammermilling test was developed in an effort to relate the hammermilling of bark (and wood) to bark strength, toughness and morphology.

As discussed in the section on Experimental Procedures, bark strength measures shear parallel to the grain while bark toughness measures the energy required to rupture a thin specimen by a bending force perpendicular to the grain (parallel to the tree diameter). Table XVI summarizes the bark strength and bark toughness tests made on the wood and bark of white birch. Earlier investigations were made into bark strength as part of Project 2929 (Report Three). Included for comparison purposes are the bark strength values for a number of pulpwood species of interest (Appendix Table XXVII).

TABLE XVI

SUMMARY OF STRENGTH AND TOUGHNESS MEASUREMENTS MADE ON WOOD AND BARK OF WHITE BIRCH[a]

Material	Strength	Toughness
Sapwood	--	0.44
Inner bark	1.6	0.10
Outer bark	9.8	0.10

[a]Determinations made on two different trees.

The bark strength of the inner bark of white birch is considerably less than that of aspen and comparable to that of sugar maple. This is probably due to the lack of phloem fibers and the presence of large amounts of sclereids in both species. The strength of the outer bark, in contrast, was much greater than that of aspen and maple. Bark toughness was similar for all three species.

Hammermilling, followed by screening, can be expected to result in only a moderate reduction in levels of bark. When the half-sized chips for the two trees investigated were hammermilled, and the material on the 14-mesh screen retained, the result was a 7% loss in wood and a 38% reduction in bark. However,

a large amount of the bark removed was inner bark. This is the fraction that contains little fiber but many sclereids and hammermilling should result in an improvement in pulp quality over no treatment. If, as in the illustration discussed for aspen, preliminary screening resulted in a fraction that was 60% wood and 40% bark, hammermilling followed by screening would result in a considerable reduction of the inner bark fraction. By saving the material greater than 14-mesh, remaining would be a mixture of 69% wood and 31% bark. The flexibility and strength of the outer bark of white birch appeared to be a factor in its being less affected by hammermilling than quaking aspen or sugar maple. Summarized in Table XVII are the results of the hammermilling tests run on white birchwood and bark. Figure 17 illustrates the effect of hammermilling on the wood and bark of white birch.

TABLE XVII

SUMMARY OF HAMMERMILLING TEST ON WHITE BIRCH

		Fraction Retained on Standard Screen[a], %						
Tree No.	Material	5 Mesh	10 Mesh	14 Mesh	20 Mesh	28 Mesh	< 28 Mesh	Remarks
3212-19	Bark	32	18	10	7	11	23	Most of the bark retained on the 5 & 10-mesh screens was outer bark; mostly inner bark on rest of screens
	Sapwood	77	13	3	2	2	3	
3212-20	Bark	36	19	10	8	7	20	Same as above
	Sapwood	75	15	4	2	1	2	
	Heartwood	63	23	6	4	2	2	

[a] Standard soil screen sizes; 5 mesh has 5 wires per inch and an opening of 4.00 mm, 10 mesh has 10 wires per inch and an opening of 2.0 mm, 14 mesh has 14 wires per inch and an opening of 1.168 mm, 20 mesh has 20 wires per inch and an opening of 1.00 mm, and the 28-mesh screen has 28 wires per inch and an opening of 0.598 mm.

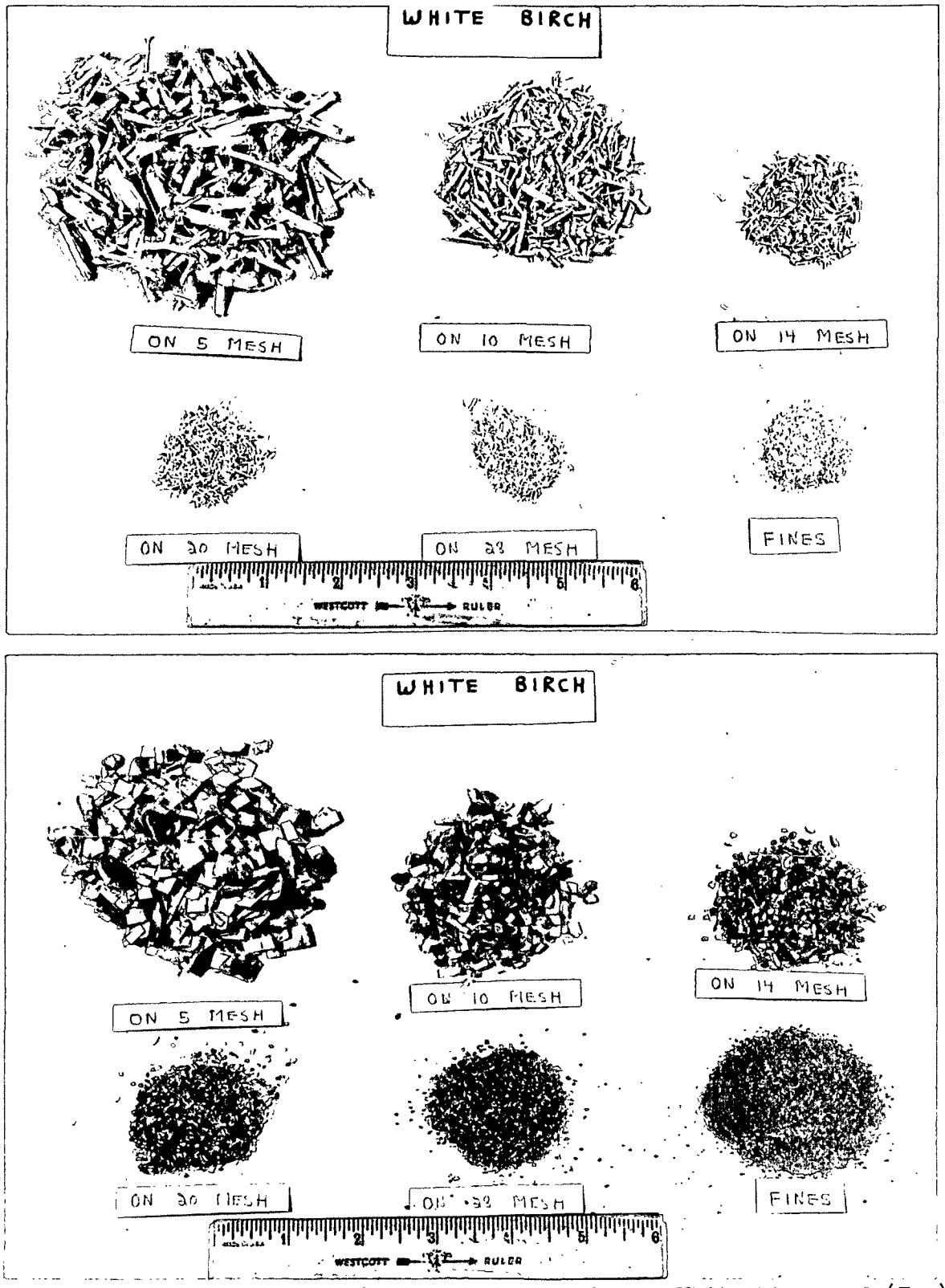

Figure 17. Illustrated is the Effect of Hammermilling on White Birchwood (Top) and Bark (Bottom). Most of the Bark Retained on the 5 and 10-Mesh Screens was Outer Bark

WATER FLOTATION BEHAVIOR

One possible method of segregating wood/bark chip mixtures is by water flotation procedures. Knowledge of the flotation characteristics of wood and bark is also expected to be important when certain types of chip washing procedures are employed. Earlier investigations into water flotation segregation (Project 2977) revealed that chip size, specific gravity, moisture content, and rate of moisture uptake were factors in the flotation behavior of bark and wood chips. Budget limitations do not permit examination of all the factors involved and, as a result, the influence of chip size has been eliminated from the variables considered.

Two procedures were used to examine the water flotation behavior of wood and bark. One procedure involved measuring the density[15] (green weight divided by green volume) of simulated chips at a number of different moisture contents. The second technique involved measuring the rate of moisture uptake and sinking of wood and bark chips in what have been designated as "dwell time" studies.

Density Determinations

Simulated chips were used in determining the relationship between moisture content and density of bark and wood. Wood and bark from two white birch trees (IPC 3212-19 and 3212-20) were used in making the determinations. The moisture content of the chip samples was adjusted by equilibrating in small jars to which had been added appropriate amounts of water. The extremely accurate pycnometer

[15]The term density is used in this report to indicate the weight of wood and bark samples and is expressed in the terms of green weight divided by green volume. This is in contrast to the term specific gravity, which also is an expression of the weight of a sample, but in this case it is in terms of dry weight divided by green volume.

method described in Experimental Procedures was used in determining density. The wood samples used included both heartwood and sapwood and, in the preliminary plotting of the wood data, it became apparent that very small density differences existed between the two types of wood. As a result, the data were handled as a single population. Bark samples used were "whole bark" samples, a combination of both inner and outer bark. Small chips of inner and outer bark were also tested.

The outer bark tended to have a considerably lower density than the inner or total bark and was very similar to the wood density. From these indications it would appear that the outer bark would float and the inner bark would sink at high moisture contents. The outer bark of white birch is also extremely water repellent and takes up moisture much less readily than the inner bark.

Figure 18 illustrates the relationship that was found between moisture content and density. The linear relationship shown was obtained by fitting the least squares regression line through the data. The dashed lines are two standard deviations above and below the average values. The standard deviation of the regression line is considerably less than would have been obtained if conventional mill-run chips had been used for the water flotation studies, because the simulated chips were uniform in size and shape, had a uniform level of moisture and were relatively free of knots, reaction wood, etc. Water segregation is believed to be possible when one fraction has a density of less than one and the other greater than one at a specific moisture content.

The data indicate that at moisture contents of between 50 and 90% most whole bark chips could be expected to sink (density greater than 1). White birch-wood, on the other hand, could be expected to float (density less than 1). In Project 2977 work it was found that, at moisture contents of 20 and 45%, the

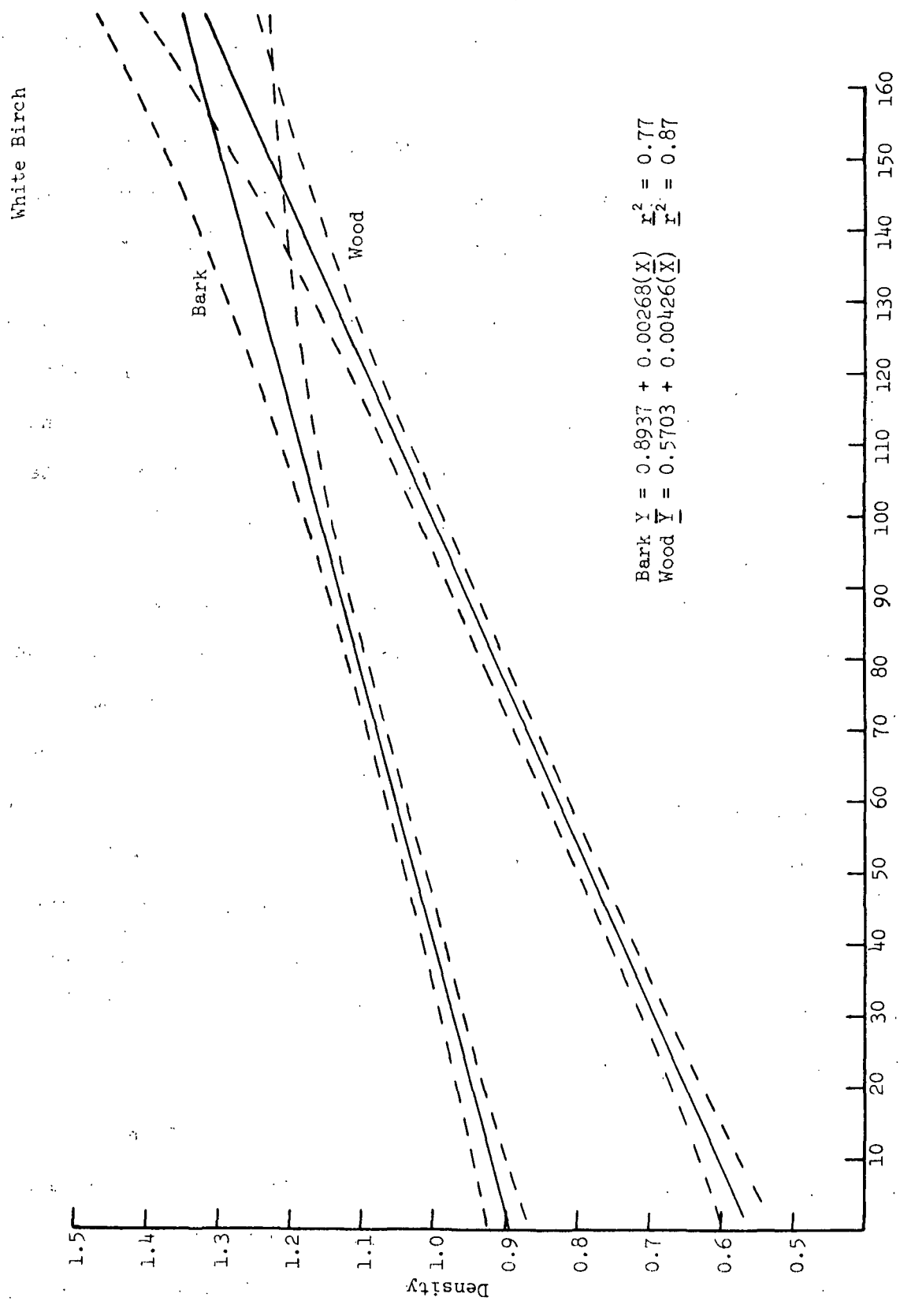

Figure 18. Illustrated is the Relationship Between Basic Density and Moisture Content for White Birch. The Dashed Lines are Two Standard Deviations Above and Below the Mean

majority of the bark floating with the wood was outer bark. Neither chip size nor moisture content had any influence on outer bark behavior. However, by beating the chips, the inner bark could be separated from the outer bark and then segregated after the inner bark sank. The floating fraction (wood + outer bark) could then be put under pressure causing the wood to sink and leaving the outer bark floating.

As mentioned in previous sections, with conventional chips not all bark chips are total bark (inner + outer bark). Some are all outer bark, some are mostly inner bark and some have wood attached. Also, the moisture content of outer bark is often less than that of inner bark when conventional chips are used. Air entrapment in bark can reduce bark specific gravity and the presence of reaction wood and stain can greatly increase wood specific gravity to the point that a certain part of the total sample will not behave as expected.

Dwell Time Investigations

An investigation of dwell time involves nothing more than taking wood and bark chips at some standard moisture content, placing them on a water surface and observing the time it takes the material to pick up enough water to sink. Information on dwell time is useful because moisture uptake rate could have a considerable influence on the success of a segregation procedure (or chip washing procedure) and would provide information on the rate at which segregation could be expected.

Half-sized simulated chips (1 x 0.3 x 0.2 inches) were used in the dwell time tests. Prior to testing, the samples were equilibrated in 50% RH and had a moisture content of approximately 20% (ovendry basis). Table XVIII summarizes the results for white birch. As was expected from previous investigations, all the wood was floating after four hours. In one instance, 40% of the bark was

still floating and, in the other, 61% was floating. This is undoubtedly due to the influence of the outer bark. Separation of the outer from the inner bark by hammermilling or a similar technique should give improved results.

TABLE XVIII

SUMMARY OF DWELL TIME RESULTS FOR WHITE BIRCH[a]

Sample No.	Time Interval, min	Sinkers, %	Floaters, %
IPC 3212-19 Sapwood	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-19 Bark	after 5	6.6	93.4
	15	6.6	93.4
	60	9.3	91.7
	240	39.1	60.9
IPC 3212-20 Sapwood	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-20 Bark	after 5	0	100
	15	0	100
	60	21.7	78.3
	240	60.3	39.7

[a]Starting moisture content 20%.

DATA INTERPRETATION

White birch inner and outer bark, although similar in specific gravity, are different morphologically. The outer bark also has a much higher bark strength and is considerably more water repellent than the inner bark.

Because of the fairly high numbers of sclereids and lack of fibers in the inner bark of white birch, removal of the inner bark seems desirable in many

instances. This can be accomplished much easier than it can be for sugar maple, although not with the variety of methods available for aspen.

Dwell time experiments showed that inner and outer bark must be separated for effective flotation segregation. This can be accomplished in several ways. Chipper action resulted in good separation which could be further enhanced by beating the chips before floating them. After the sinking inner bark was removed from the system, the chips could be put under pressure, causing the wood to sink and leaving the outer bark floating. Using the pressure system may not be a feasible procedure due to its complicated nature.

Hammermilling is a good way to remove the inner bark if water flotation is not desirable. Most of the inner bark is broken up into very small particles by the hammermilling action and can then be removed or concentrated in one or two small-sized chip fractions by screening.

It is possible that, for some products, white birch bark could be pulped with the wood. The yield would be reduced considerably because white birch bark contains no fibers and only a small amount of filler-type material. However, one of the major problems with birch bark is sclereids and most of the bark material, including sclereids, would be lost in washing and handling operations.

RELATED LITERATURE

During the process of reviewing and assembling the information on the bark and wood of white birch, a number of papers containing related information were reviewed. These papers are described in the paragraphs that follow.

An additional reference on seasonal variation in wood/bark adhesion is: Wilcox, et al. (33).

The relationship between bark thickness and the diameter of bolts is covered in a paper by Hale, J. D. (32). Amounts of bark as a percentage of rough tree weight can be found in the paper by Besley (10). F. M. Womeldorff discusses the feasibility of separating heartwood from sapwood chips (41).

BARK AND WOOD PROPERTIES OF NORTHERN RED OAK (Quercus ruba L.) (Q. borealis Michx.)

SILVICULTURAL CHARACTERISTICS AND GEOGRAPHIC RANGE

Northern red oak, a widely distributed tree in the Eastern United States, is common east of the Mississippi River except in Florida and the coastal areas of other Gulf and South Atlantic states. Its range extends north to southeastern Canada, west through Minnesota and continues south through eastern Oklahoma.

Tolerant of wide environmental variations, red oak grows best on the west slope of the Alleghenies in the Ohio Valley with an average annual precipitation of 40 inches, a mean annual temperature of 55 degrees, and 160 frost-free days. Reaching a normal height of 70 to 90 feet and a diameter of 2 to 3 feet, in this region, a height of 160 feet and diameters of 5 feet can be obtained. Although red oak will grow in a wide range of soils, varying from clay to loamy sands, and from deep, stone-free to shallow rocky soils, the general topography, types and depths of the soil and availability of moisture affect the site quality. Fine-textured soil and topography that favors a relatively high water table characterize the best sites for northern red oak.

WOOD AND BARK MORPHOLOGY

Wood (Xylem)

Hard and heavy, (specific gravity 0.52-0.61 green, 0.62-0.76 ovendry) (42), the heartwood of the red oak appears pinkish to pale reddish brown. A ring-porous wood, the growth rings are very distinct and earlywood (springwood) pores are large, forming a conspicuous band 1-4 pores in width. The transition to latewood (summerwood) is gradual to more or less abrupt, and the pores are more abundant, round, small, thick-walled and less distinct. The largest vessels are

200-430 μm in diameter in the earlywood, and number 10-30 per sq mm in the latewood. Rays, also conspicuous to the naked eye, are unstoried, homogeneous, and of two types. The broad rays are approximately 12-30 seriate and 150-400+ μm in diameter. On a tangential surface, these broad rays are separated by numerous narrow rays, usually uniseriate and very variable in height, 1-20+ cells. Paratracheal parenchyma intermingle with tracheids, forming part of the conjunctive tissue between the earlywood pores and the rays, and composing most of the light-colored tissue in the latewood vessel area. Very abundant, the parenchyma are usually metatracheal or metatracheal-diffuse, usually zonate in fine, more or less regular, tangential lines in the outer portion on the ring. Red oak fibers, medium thick to thick-walled, measure 14-22 μm in diameter and average 1.4 mm in length.

Bark (Phloem)

The outer bark of the mature northern red oak forms shallow and broad fissures with wide and flat-topped ridges and is firm, rather hard and dark brown. The inner bark (secondary phloem) is light yellowish-red and is as wide or wider than the total thickness of the rhytidome. Broad phloem rays and more or less curved sclerenchyma lines are visible to the naked eye. Trunks of young trees are smooth and grayish-brown. Figure 19 illustrates the appearance of the major elements of the wood and bark of northern red oak. The percentages of inner and outer bark on pulpwood-sized trees (6-10 inches dbh) can vary greatly, ranging from 20% inner bark in very rough fissured areas to 85% inner bark where the bark is relatively smooth.

Anatomical Structure of Young Bark

The outer bark consists of a layer of compactly arranged epidermal cells, thin-walled phellem cells, a cortical region with collenchyma and parenchymatous cells, and well-developed phloem fibers. Usually in 4-6 layers, these

fibers encircle the phloem tissues in archlike bands connected to one another with some sclereids between these "arches." Sieve tubes, parenchyma, and phloem rays make up the secondary phloem.

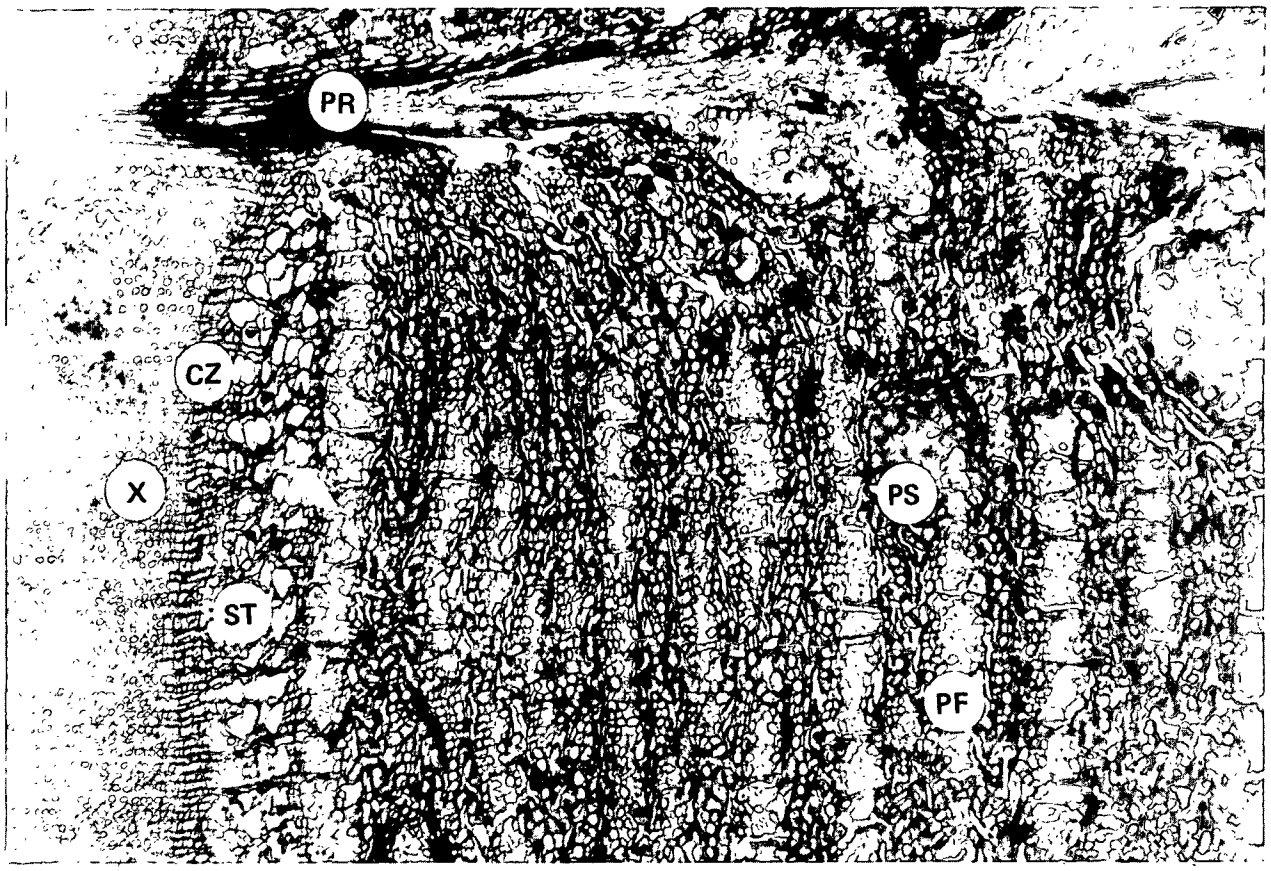

Figure 19. Cross Section of Quercus rubra with (Left to Right) Xylem (X), Cambium Zone (CZ) and Inner Bark. A Broad Ray (PR) is Illustrated on the Upper Left-Hand Side of the Figure. The Sieve Tubes (ST) are Mostly Crushed in Different Degrees Except the Last-Formed Cells Close to the Cambium. Also Illustrated are Phloem Fibers (PF) and Phloem Sclereids (PS). Magnification — 75X

Anatomical Structure of Mature Bark

Northern red oak periderm is composed of well-developed suberized phellem cells with comparatively thick cell walls. The formation of layers is often irregularly spaced and the layers are tangentially extended as the phloem

rays seldom extend through the periderm. As a result, the rhytidome is comparatively narrow and the periderm layers are inconspicuous.

Sieve tubes, parenchyma and sclerenchyma cells, and phloem rays compose the inner bark or secondary phloem. Outside the last-formed periderm, these secondary phloem tissues are mostly "lignified" and enlarged cells mixed with sclereid groups. The significant transformation occurs in the parenchyma and ray cells. The sieve tubes in this area are usually crushed and the phloem fibers are less abundant.

Confined by the phloem rays, parenchyma and schlerenchyma cells, the sieve tubes are in groups of 4 to 10 and vary in length from 240-655 µm, with a mean of 428 µm. The sieve tubes are crushed to different degrees with the general exception of the last-formed band or bands close to the cambium.

Sclerenchyma appear in the form of phloem fibers and sclereids. Phloem fibers develop and mature very close to the cambium, often in the current growth season, and form up to 6 layers aligned in discontinuous tangential bands contiguous to the crystalliferous parenchyma cells. Fibers are polygonal in cross section and taper gradually to pointed ends, varying from 0.57 to 1.47 mm in length, with a mean of 1.06. Having a very narrow lumen, about 2 µm in diameter, a cross section of the widest portion of the fiber is about 15-25 µm. At an old growth region, a fiber-band may connect with a sclereid-band. Mature sclereid groups appear rather far from the cambium in northern red oak except for those in the broad rays. These groups may be tangentially elongated and form short bands. Sclerenchyma between two dilated broad rays is composed mostly of fibers with scattered sclereids, and due to the wide dilation of the broad rays, the sclereid-groups at the outer portion of the inner bark and rhytidome portion appear in more sporadic fashion.

Phloem rays are of two types. The narrow rays are homogeneous, usually uniseriate, and most about 12 cells or 150-200 µm high. The broad rays, also homogeneous, may be 30-seriate and become dilated rather early and spread open quite wide at the outer part of the secondary phloem. This often causes an arch-shaped pattern in the other secondary phloem tissues. Cells often become "lignified" starting at about the middle portion of the broad rays, and these "lignified" or sclereid-groups appear at regular intervals along the radius. These cells become very thick and usually retain their original size and shape but may expand and become irregular.

SPECIFIC GRAVITY, EXTRACTIVES AND FIBROUS YIELD

As discussed in the quaking aspen, sugar maple, and white birch sections, basic information on such bark properties as specific gravity, level of extractives, fiber yield and the presence of such morphological elements as phloem fibers and sclereids are expected to be useful in determining the need and possible methods of separating and segregating wood/bark chip mixtures[16]. Whenever possible, data on bark have been compared with similar information on wood.

Specific Gravity

Specific gravity of bark and wood of northern red oak has been measured by a number of individuals. The variation exhibited by the data can be attributed to genetic and geographic differences and also to measurement techniques[17] and different ways of expressing the data. Table XIX summarizes the information

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[16] Throughout this report the term separation has been used to designate separation or detachment of wood from bark while segregation has been used to indicate removal of either the bark or wood fraction from wood/bark chip mixtures.

[17] Increment core data, for example, tends to weight the center of the tree more heavily than the area near the cambium while disks and wedge-shaped samples provide representative values.

available and, whenever possible, information on bark is separated into inner and outer bark. Specific gravity is most often expressed as ovendry weight over green volume. Information expressed in terms of green weight over green volume is particularly useful when examining the possibilities of liquid flotation as a means of segregating wood/bark chip mixtures. Information in this report under the section Water Flotation Behavior compares the basic density (green weight divided by green volume) of northern red oak at several moisture contents.

TABLE XIX

NORTHERN RED OAK SPECIFIC GRAVITY INFORMATION

Wood		Bark				
Average	Range	Inner	Outer	Total	Range	Reference & Remarks
			0.64		0.63-0.64	Fournier & Goulet (12)
0.56	0.56-0.57					Besley (U.S.) (10)
0.58						Besley (Canada) (10)
0.57						Isenberg (9)
0.528 (sapwood)		0.477	0.753	0.634		IPC 3212-1
0.576 (heartwood)						
0.502 (sapwood)		0.493	0.744	0.643		IPC 3212-7
0.558 (heartwood)						
		0.612	0.702	0.674		IPC 3212-9
				0.786[a]		Harkin & Rowe (17)

[a]Ovendry weight/ovendry volume.

An average specific gravity (ovendry weight/green volume) of approximately 0.56 appears appropriate for the wood of northern red oak. Our limited data show the heartwood to be higher in specific gravity than the sapwood although more trees would have to be sampled to determine whether this is a definite trend.

The specific gravity of the total (inner + outer) bark of northern red oak appears slightly higher than that of wood, although probably not enough to effect segregation in a water flotation procedure. However, moisture content of the chips would also affect the results as was the case when investigated under

the section "Density Determinations." Overall values suggested for use in species comparisons are 0.56 for wood, and 0.53, 0.71 and 0.65 for inner, outer, and total bark.

Extractives

Extractives in wood and bark are important because, when present in large amounts, they not only result in reduced yield of fibrous material but ultimately can be expected to result in paper machine "pitch problems." Recent needs to reduce total water use through closed white water systems are expected to accentuate problems in this area. No attempt has been made in this report to go beyond determining the total alcohol-benzene extractives. Such extractives information is expected to provide an appropriate indication regarding possible pitch problems when large amounts of bark are pulped. Further detailed examination of the types of extractives involved is recommended using specific bark sources if preliminary comparisons suggest pitch and yield problems may develop.

Table XX summarizes available information on extractives levels in the bark of northern red oak and includes two trees (3212-7 and 3212-9) sampled as part of this project. Extractives levels in the bark of northern red oak are intermediate, more than the level found in sugar maple but less than that found in quaking aspen and white birch. This level of extractives is not expected to be a serious problem except in those instances where high percentages of bark have been concentrated in a particular chip fraction by screening or other mechanical techniques.

Fibrous Yield

Increasing emphasis is being placed on pulping bark rather than debarking bolts or segregating wood/bark chip mixtures. Important to determining the

usefulness of this approach with a particular species is determining the proportion of lignified cells that exist in the bark and that will survive normal cooking procedures. Also, it is important to determine what these cells will contribute in a favorable way to the resulting paper product.

TABLE XX

NORTHERN RED OAK ALCOHOL-BENZENE EXTRACTIVES

Type of Material	Extractives, %	Sources
Wood	4.1	Isenberg (9)[a]
Wood	4.6	Barker (43)[a]
Bark	12.7	Harkin & Rowe (17)
Bark	10.3	IPC 3212-7
Bark	9.8	IPC 3212-9

[a]Isenberg's value is the average of blackjack oak, chestnut oak, and post oak, while Barker's value is from willow oak.

There is a high percentage of sclereids in the inner bark of northern red oak but there is also a certain amount of fibrous material. Sclereids are short, thick-walled, heavily lignified cells often found in clumps. Estimates made on macerated bark samples suggest that they make up about 12% of the bark total weight. When not fully cooked, as could occur in high-yield pulping, clumps of sclereids may cause so-called "fish-eyes" in certain grades (calendered) of paper. Levels of sclereids are high in northern red oak whole bark when compared to aspen. However, a greater proportion of these sclereids are lost when the bark is pulped.

As described in the section on Bark Morphology, there occurs in the inner bark (secondary phloem) bands of heavily lignified fibers described in the literature as phloem fibers or sclerenchyma fibers. These fibers are the

principal bark elements expected to survive chemical pulping and contribute to overall pulp yield and sheet strength. Chang (1) estimated that 12.4% of the inner bark of northern red oak was composed of phloem fibers based upon examination of cross sections. As a further check on pulp yield and the nature of fibrous material produced, 20 to 30-gram samples were pulped using the IPC Standard Kraft Micropulping Procedure. For a complete description see the section on Experimental Procedures. Table XXI summarizes the results of this investigation. Figure 20 illustrates the type of material found on the 60- and 150-mesh screens.

The micropulping results suggest that, when red oak bark samples composed of about 40% inner bark and 60% outer bark are pulped, a solids yield of about 28% will be obtained. Examination of the composition of the solids reveals that the material is composed of fibers, sclereids, sieve tubes, and miscellaneous parenchyma cells. For every 100 grams of northern red oak bark pulped, it appears there will be produced about 5 grams of fiber, 12 grams of sclereids and 12.5 grams of sieve tubes and parenchyma cells. When screened and only the fractions that are retained on the 60 and 100-mesh screens are considered (fractions that are assumed will end up in the paper furnish), 100 grams of bark will produce 4.6 grams of fiber, 1 gram of thin-walled parenchyma cells and 0.2 gram of sclereids.

WOOD/BARK ADHESION

Wood/bark adhesion differences have been suggested as one of the reasons for differences encountered in the ease of debarking pulpwood species. The same factors influencing debarking of pulpwood are expected to influence debarking of wood chips. The approach taken in the study has been to obtain growing season and dormant season information on (1) magnitude of wood/bark adhesion,

(2) morphological structures associated with wood/bark adhesion, and (3) reasons for differences between species in adhesion.

TABLE XXI

NORTHERN RED OAK MICROPULPING INVESTIGATION

Data	Sample No. 3212-7	Sample No. 3212-9	Remarks
Yield, % solids	29.4	30.2	Third sample gave 25.4% yield
Fraction			
on 60 mesh, %	13.2	9.6	Fraction contained principally phloem fibers (90-95%) with small percentages of sieve tubes (< 5%), sclereids (< 5%) and crystalliferous parenchyma (< 5%). The average arithmetic length of phloem fibers was 1.04 mm
on 100 mesh, %	6.2	4.2	Fraction contained large percentages of phloem fibers (50-60%) and sieve tubes (30-40%) with small percentages of parenchymatous cells (5-10%), sclereids (< 5%) and crystalliferous parenchyma (< 5%). The average arithmetic length of sieve tubes was 0.61 mm
on 150 mesh, %	5.2	4.0	Fraction contained principally sieve tubes (40-50%) and parenchymatous cells (30-40%) with smaller percentages of phloem fibers (10-20%), sclereids (5-10%) and crystalliferous parenchyma (< 5%)
on 200 mesh, %	5.8	6.2	Fraction contained large percentages of parenchymatous cells (30-40%), sieve tubes (30-40%) and sclereids (20-30%) with small percentages of phloem fibers (< 5%) and crystalliferous parenchyma
through 200 mesh, %	69.6	76.0	Fraction contained principally sclereids (50-60%) and parenchymatous cells (30-40%) with small percentages of crystalliferous parenchyma (5-10%) and sieve tubes (< 5%)

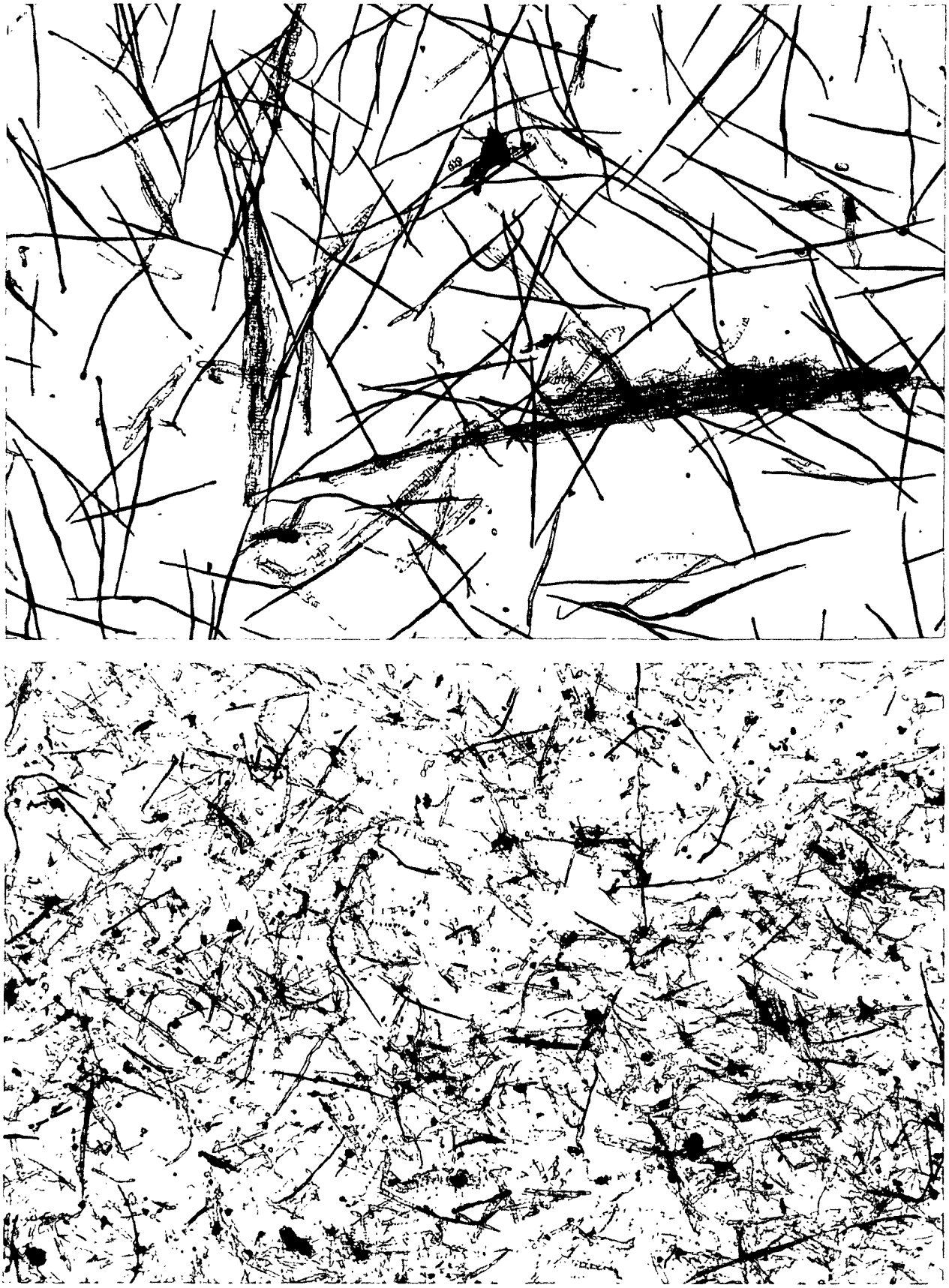

Figure 20. The 60-Mesh Screen (Top) Contained Primarily Phloem Fibers (90-95%) with Very Small Amounts of Sclereids (< 5%). The 150-Mesh Screen (Bottom) Contained a High Percentage of Sieve Tubes (40-50%) with Smaller Percentages of Parenchymatous Cells (30-40%), Phloem Fibers (10-20%) and Sclereids (5-10%). Magnification — 35X

Wood/bark adhesion values were measured for northern red oak samples collected in July (growing season) and September (dormant season). After testing, the samples were examined to determine the location of the zone of failure. Figure 21 illustrates the zone of failure for northern red oak during both the growing and dormant seasons. During the growing season, wood/bark adhesion was very low (2.5 kg/cm^2) and the failure zone was located between the cambium zone and the adjacent last-formed immature xylem cells. During the dormant season, wood/bark adhesion increased to 8.4 kg/cm^2 and the failure zone was located in the inner bark, primarily between the collapsed phloem sieve tubes and parenchyma cells adjacent to the more recently formed tangential bands of phloem fibers close to the cambium.

Northern red oak wood/bark adhesion values were lower than for most of the other species tested so far (see Appendix Table XXVI). Low dormant season test values seem to be associated with the presence of sclereids and low numbers of fibers in the inner bark.

As discussed in preceding sections, a number of methods to reduce adhesion were investigated in Project 2929 work. They included several chemical, thermal, and biological methods. The use of green kraft cooking liquor at a temperature of 200°F and a treatment time of 60 minutes gave reduced adhesion. The main disadvantage was the high temperatures and long treatment time required. Chemical treatments were also investigated by Haas and Kremers (27) and, in their work, dilute acids were effective in reducing adhesion. The principal disadvantage of this treatment was the length of time required to effect separation, the discoloration of the wood of some species and the ineffectiveness of the treatment on dry samples.

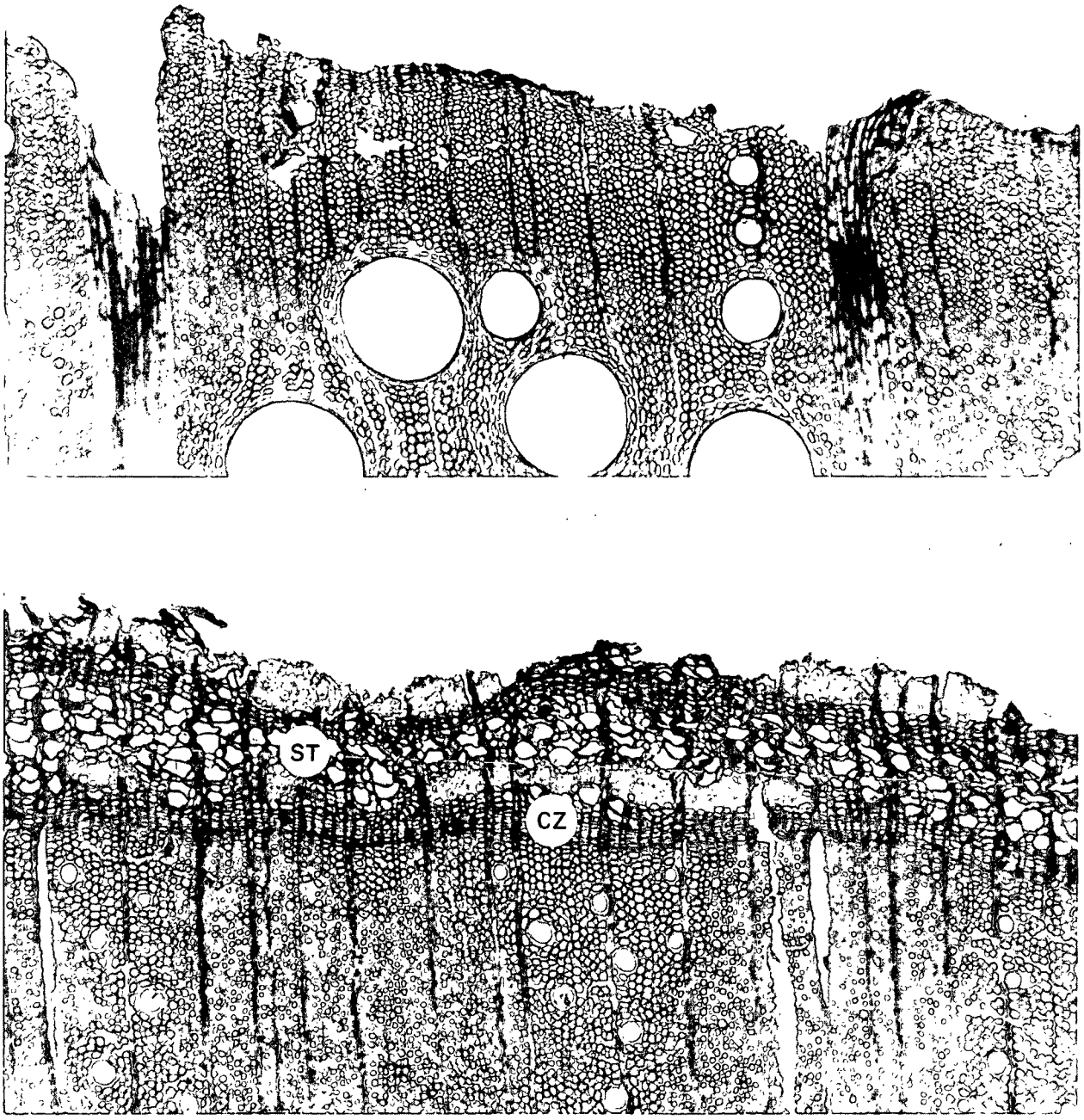

Figure 21. Zones of Failure in Northern Red Oak are Illustrated for the Growing Season (Top) and Dormant Season (Bottom). The Growing Season Failure Zone was Located Between the Cambium Zone and the Adjacent Last-Formed Immature Xylem Cells. Failure During the Dormant Season Occurred in the Inner Bark, Primarily Between the Collapsed Phloem Sieve Tubes and Parenchyma Cells Adjacent to the More Recently Formed Tangential Bands of Phloem Fibers Close to the Cambium. Magnification — 75X

Pressure chamber treatments also looked promising with reduced treatment time needed when temperatures were in excess of 250°F. Moist storage of chips at temperatures that encourage fungus attack of the cambium zone resulted in greatly reduced wood/bark adhesion at storage times as short as 15-20 days. Another promising approach was the use of microwave heating to create high temperatures in the moist interior of the chips. There was a moderate reduction in wood/bark adhesion at treatment times as short as one minute.

BARK STRENGTH, TOUGHNESS AND REACTION TO HAMMERMILLING

Bark strength and toughness measurements are included as part of the characterization of bark because it was felt that when these measurements are compared with the results obtained in wood/bark adhesion tests, with the difficulty encountered in conventional debarking and with bark morphology, the "why" of bark separation and segregation would eventually emerge.

Hammermilling has been widely used in bark utilization to prepare fractions for use as horticultural mulch, soil conditioners, and as additives to a number of types of products. A simulated hammermilling test was developed in an effort to relate the hammermilling of bark (and wood) to bark strength, toughness, and morphology.

As discussed in the section on Experimental Procedures, bark strength measures shear parallel to the grain while bark toughness measures the energy required to rupture a thin specimen by a bending force perpendicular to the grain (parallel to the tree diameter). Table XXII summarizes the bark strength and bark toughness tests made on the wood and bark of northern red oak. Also included for comparison purposes (Appendix Table XXVII) are the bark strength values for a number of pulpwood species of interest.

TABLE XXII

SUMMARY OF STRENGTH AND TOUGHNESS MEASUREMENTS MADE ON WOOD AND BARK OF NORTHERN RED OAK[a]

Material	Strength	Toughness
Sapwood	--	0.42
Inner bark	2.1	0.12
Outer bark	4.6	0.16

[a]Determinations made on two different trees.

The inner bark strength of northern red oak is considerably less than that of aspen but more than sugar maple and white birch. This is probably due to the presence of some phloem fibers in the inner bark of northern red oak. Sugar maple and white birch have essentially no fibers in the inner bark and aspen has greater numbers than oak.

Hammermilling, followed by screening, can be expected to result in only a moderate reduction in levels of bark. When the half-sized chips for the two trees investigated were hammermilled, and the material on the 14-mesh screen retained, the result was a 10% loss in wood and a 34% reduction in bark. The bark removed seemed to be mostly outer bark. Since the inner bark has a specific gravity near that of the wood, hammermilling followed by water flotation would not, in all probability, result in effective segregation. However, the fiber contained in the inner bark could be of some value. Summarized in Table XXIII are the results of the hammermilling tests run on northern red oak wood and bark. Figure 22 illustrates the effect of hammermilling on wood and bark of northern red oak. The high amount of wood loss was surprising considering the high specific gravity and medium high toughness of northern red oak wood.

TABLE XXIII

SUMMARY OF HAMMERMILLING TEST ON NORTHERN RED OAK

Tree No.	Type Material	Fraction Retained on Standard Screen[a], % 5 Mesh	10 Mesh	14 Mesh	20 Mesh	28 Mesh	< 28 Mesh	Remarks
3212-1	Bark	21	28	12	9	11	19	Half of material on 5 & 10-mesh screens inner bark; 65+% outer bark on other screens
	Heartwood	63	23	5	2	2	4	
	Sapwood	63	23	5	3	2	4	
3212-7	Bark	34	26	11	6	7	15	Same as above
	Heartwood	54	30	7	3	2	5	
	Sapwood	56	26	7	3	3	5	

[a] Standard soil screen sizes; 5 mesh has 5 wires per inch and an opening of 4.00 mm, 10 mesh has 10 wires per inch and an opening of 2.0 mm, 14 mesh has 14 wires per inch and an opening of 1.168 mm, 20 mesh has 20 wires per inch and an opening of 1.00 mm, and the 28-mesh screen has 28 wires per inch and an opening of 0.589 mm.

WATER FLOTATION BEHAVIOR

One possible method of segregating wood/bark chip mixtures is by water flotation procedures. Knowledge of the flotation characteristics of wood and bark is also expected to be important when certain types of chip washing procedures are employed. Earlier investigations into water flotation segregation (Project 2977) revealed that chip size, specific gravity, moisture content and rate of moisture uptake were factors in the flotation behavior of bark and wood chips. Budget limitations do not permit examination of all the factors involved and, as a result, the influence of chip size has been eliminated from the variables considered.

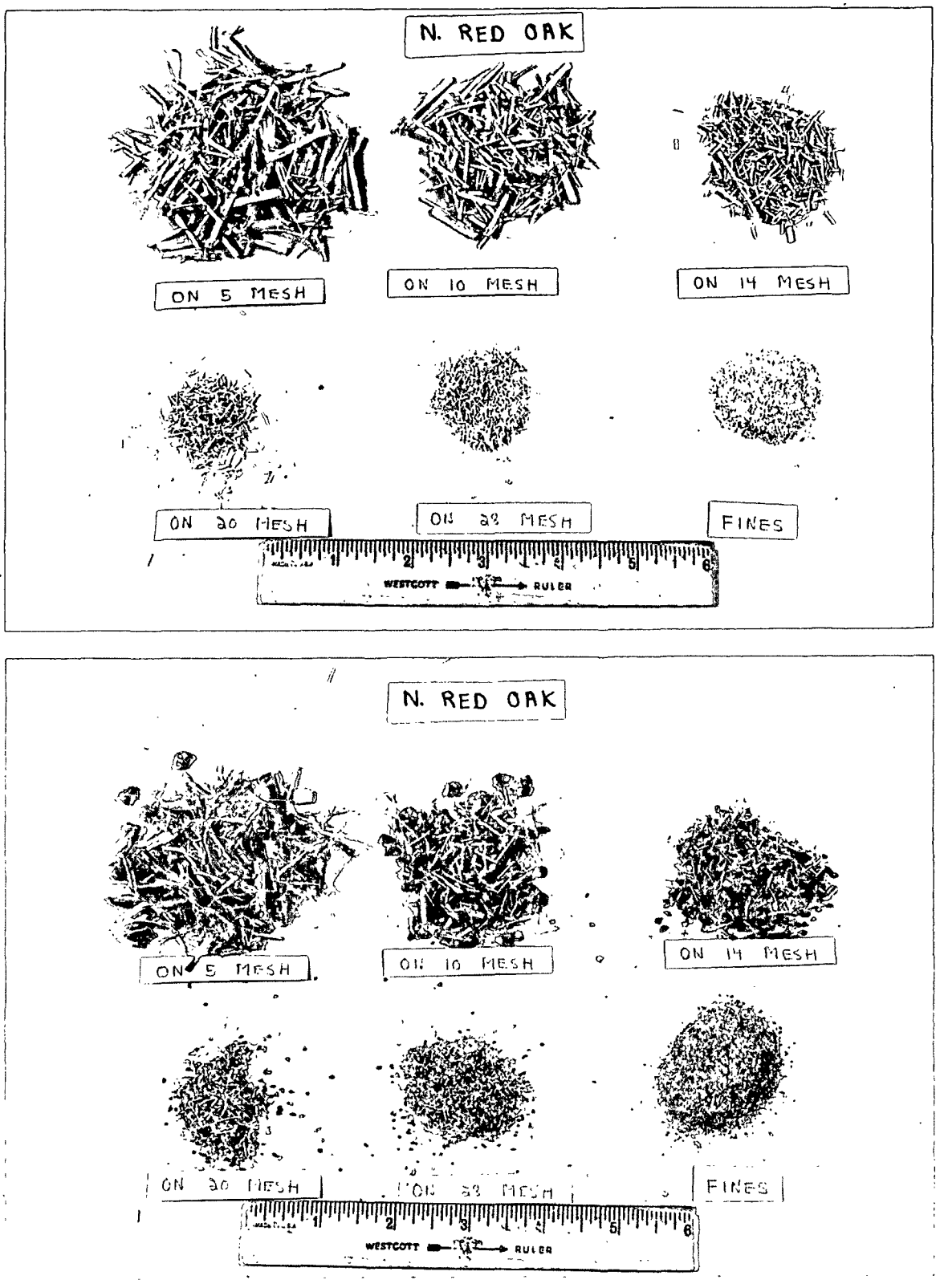

Figure 22. Illustrated is the Effect of Hammermilling on Northern Red Oak Wood (Top) and Bark (Bottom)

Two procedures were used to examine the water flottion behavior of wood and bark. One procedure involved measuring the density[18] (green weight divided by green volume) of simulated chips at a number of different moisture contents. The second technique involved measuring the rate of moisture uptake and sinking of wood and bark chips in what have been designated as "dwell time" studies.

Density Determinations

Simulated chips were used in determining the relationship between moisture content and density of bark and wood. Wood and bark from two northern red oak (3212-1 and 3212-7) were used in making the determinations. The moisture content of the chip samples was adjusted by equilibrating in small jars to which had been added appropriate amounts of water. The extremely accurate pycnometer method described in the Experimental Procedures was used in determining density. The wood samples used included both heartwood and sapwood and, in the preliminary plotting of the wood data, it became apparent that only very small density differences existed between the two types of wood. As a result, the data were handled as a single population. Bark samples used were "whole bark" samples, a combination of both inner and outer bark. Small chips of inner and outer bark were also tested. The inner bark tended to have only a slightly lower density than the outer bark. There basically was not much difference between inner, outer, and total bark and the wood samples.

[18]The term density is used in this report to indicate the weight of wood and bark samples and is expressed in the terms of green weight divided by green volume. This is in contrast to the term specific gravity, which also is an expression of the weight of a sample, but in this case it is in terms of dry weight divided by green volume.

Figure 23 illustrates the relationship that was found between moisture content and density. The linear relationship shown was obtained by fitting the least squares regression line through the data. The dashed lines are two standard deviations above and below the average values. The standard deviation of the regression line is considerably less than would have been obtained if conventional mill-run chips had been used for the water flotation studies, because the simulated chips were uniform in size and shape, had a uniform level of moisture and were relatively free of knots, reaction wood, etc. Water segregation is believed to be possible when one fraction has a density of less than one and the other greater than one at a specific moisture content.

The data indicate that, at moisture contents of between 50 and 70%, most whole bark chips could be expected to sink (density greater than 1). Northern red oak wood, on the other hand, could be expected to float (density less than 1). This would be a rather small moisture content range for water flotation work. However, if this range of moisture content could be achieved, it appears that segregation would be possible between the wood and whole bark chips.

As mentioned previously, with conventional chips not all bark chips are total bark (inner + outer bark). Some are all outer bark, some are mostly inner bark and some have wood attached. Also, the moisture content of outer bark is often less than that of inner bark when conventional chips are used. Air entrapment in bark can reduce bark specific gravity and the presence of reaction wood and stain can greatly increase wood specific gravity to the point that a certain part of the total sample will not behave as expected.

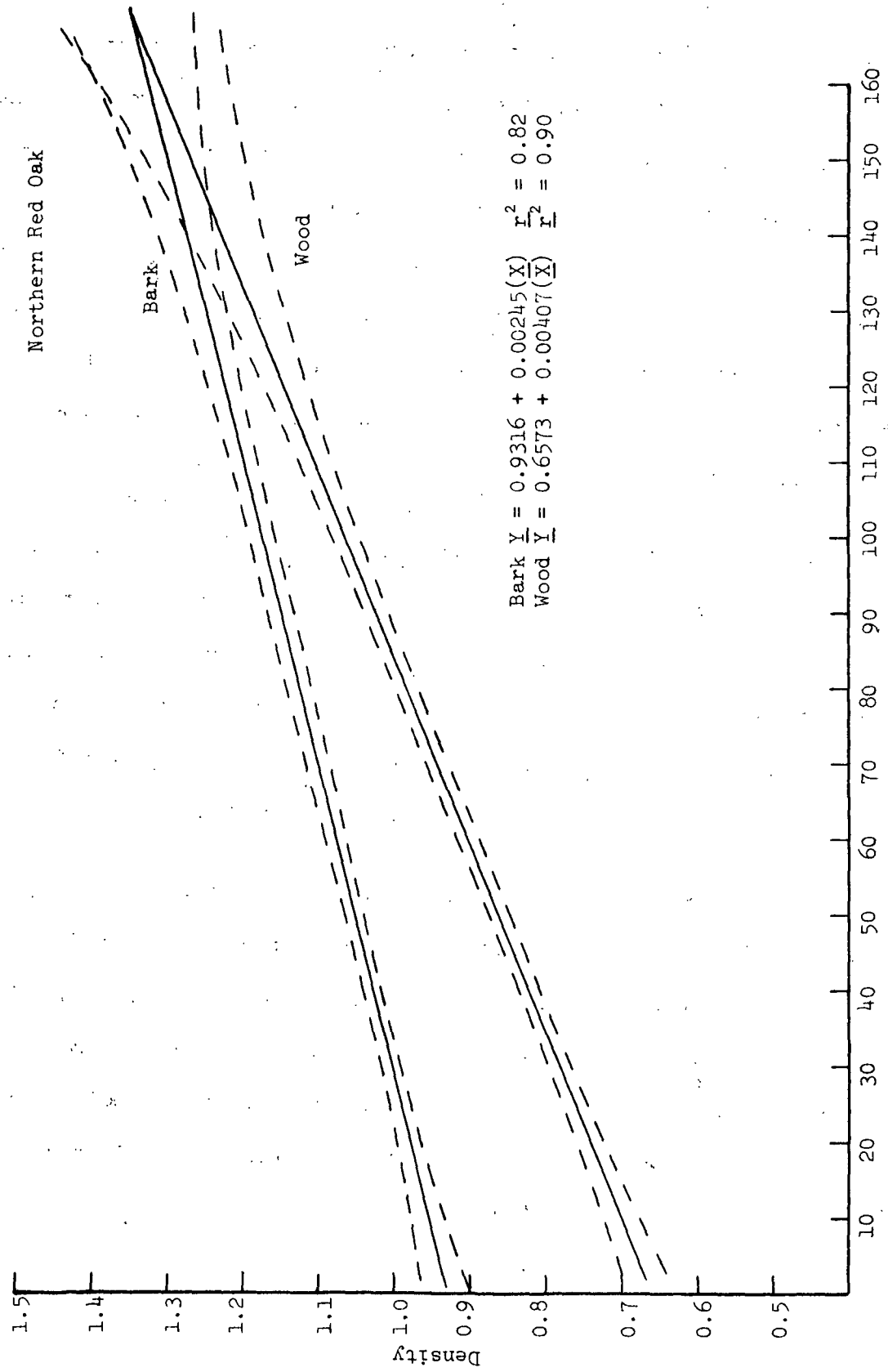

Figure 23. Illustrated is the Relationship Between Basic Density and Moisture Content for Northern Red Oak. The Dashed Lines are Two Standard Deviations Above and Below the Mean

Dwell Time Investigations

An investigation of dwell time involves nothing more than taking wood and bark chips at some standard moisture content, placing them on a water surface and observing the time it takes the material to pick up enough water to sink. Information on dwell time is useful because moisture uptake rate could have a considerable influence on the success of a segregation procedure (or chip washing procedure) and would provide information on the rate at which segregation could be expected.

Half-sized simulated chips (1 x 0.3 x 0.2 inches) were used in the dwell time tests. Prior to testing, the samples were equilibrated in 50% RH and had a moisture content of approximately 20% (ovendry basis). Table XXIV summarizes the results for northern red oak. As was expected, all the wood was floating after four hours. In one instance, 13% of the bark was still floating and, in the other, 28.5% was floating. These results could be expected to improve (less time for bark to sink) at moisture contents of between 50 and 70% as shown by the density determinations. The success of the segregation by flotation is better than expected based upon the moisture content density measurements. The reason is the difference in the rate at which the wood and bark samples of red oak picked up moisture.

DATA INTERPRETATION

How best to upgrade the quality of northern red oak wood/bark chip mixtures is not entirely clear. None of the available methods are without some disadvantages and there are several approaches that give reasonable results. Data are not available on the effectiveness of "chipper action" on the separation of bark from the wood of northern red oak during the dormant season. IPC experience

with white oak and other species having high wood specific gravity suggests that good separation is obtained from the impact of the chipper knives when thick-barked high specific gravity species such as oak are involved[19].

TABLE XXIV

SUMMARY OF DWELL TIME RESULTS FOR NORTHERN RED OAK[a]

Sample No.	Time Interval, min	Sinkers, %	Floaters, %
IPC 3212-7 Sapwood	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-7 Heartwood	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-7 Bark	after 5	7.5	92.5
	15	22.9	77.1
	60	42.0	58.0
	240	86.9	13.1
IPC 3212-9 Sapwood	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-9 Heartwood	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-9 Bark	after 5	0	100
	15	2.4	97.6
	60	15.9	84.1
	240	71.5	28.5

[a]Starting moisture content 20%.

[19]IPC Project 2929, Progress Report Two (p. 41-2).

Specific gravity, dwell time and density regression line data for bark and wood indicate a satisfactory water flotation procedure for northern red oak could be developed. The greatest difficulty appears to be the relatively narrow range of moisture contents at which the system would work (30-60%). Green, fresh-cut chips would normally be at about 100% moisture (dry weight basis) and would need to be dried down to a 50-60% moisture content in order to effect a reasonable degree of segregation.

Hammermilling, because of the high wood loss, does not appear to be satisfactory. The most promising mechanical approach appears to be to first try to concentrate the bark into one or two small-sized chip fractions by screening. The U.S.F.S. compression debarking technique (31) could then be employed to upgrade those fractions high in bark.

Another attractive alternative would be to pulp the bark. Bark micro-pulping results indicate that screening of the pulp will remove most of the sclereids and result in the production of 4-5% yield of usable fibrous material. Digester capacity, recovery furnace capacity and pulp cleaner capacity would be factors influencing the choice of this approach.

RELATED LITERATURE

There was not a lot of literature available on northern red oak and most of it has been cited in the description of bark and wood properties of northern red oak. One additional reference dealing with the separation of heartwood and sapwood chips through flotation is Womeldorff (41).

BETWEEN-SPECIES COMPARISONS

The table included in this section was prepared to provide a method of quickly comparing the basic bark information available for selected pulpwood species. It is hoped that, as the work on additional species is completed, patterns of similarities and differences will develop that will increase our understanding of hardwood and conifer bark. Because of the limited number of species investigated to date, little can be said in this regard at this time. Of the species studied to date, it appears that all four (quaking aspen, red oak, sugar maple and white birch) could be pulped without debarking with little in the way of extractives or sclereid problems. Quaking aspen bark had the greatest amount of usable fiber. Table XXV compares the measurement data available for the first four species investigated in Project 3212.

TABLE XXV

WOOD AND BARK CHARACTERISTICS OF PULPWOOD SPECIES

Characteristic	Quaking Aspen	Sugar Maple	White Birch	Northern Red Oak
Specific gravity (ovendry wt./green volume)				
Wood	0.38	0.59	0.49	0.56
Whole bark	0.50	0.54	0.56	0.65
Inner bark	0.40	0.69	0.57	0.53
Outer bark	0.55	0.49	0.54	0.71
Extractives, %				
Wood	3	1	4	4.5
Bark	15	6	17	11
Density at 100% moisture (green wt./green volume)				
Wood	0.79	1.24	1.01	1.06
Bark	1.15	1.08	1.16	1.18
Pulp yield, % (bark)	33.8	33.9	36.3	28.4
Usable bark fiber, %[a]	10	3	0	5
Sclereids remaining, %[a]	1	0.2	0.7	0.2
Fiber location[b]	IB	IB	--	IB
Sclereid location[b]	IB	IB	IB	IB
Wood/bark adhesion, kg/cm^2				
Growing season	6.4	5.8	5.1	2.5
Dormant season	11.4	10.1	12.0	8.4
Bark strength, kg/cm^2				
Inner bark	9.0	1.4	1.6	2.1
Outer bark	4.9	4.7	9.8	4.6
Toughness				
Inner bark	0.18	0.21	0.09	0.12
Outer bark	0.10	0.10	0.11	0.16
Sapwood	0.30	0.62	0.44	0.42
Hammermilling[c]				
Bark removed, %	34	29	38	34
Wood loss, %	5	5	6	10

[a] Usable bark fiber and sclereids remaining are the fibers and sclereids retained on the 60- and 100-mesh screens. The percentage given is the yield based on whole bark samples.

[b] Major proportion located in either the inner bark (IB) or outer bark (OB).

[c] Based upon simulated hammermilling followed by screening, using the on 14-mesh screen to remove bark and recover usable fiber from fines.

PLANS

Plans are to cover characterization of the sixteen species involved in this project in four reports. The second report, scheduled for completion approximately the end of January, will cover loblolly pine, slash pine, Douglas-fir, and western hemlock. Covered in the third report will be sweetgum, southern red oak, white oak, and silver maple. White spruce, jack pine, balsam fir, and eastern cottonwood will be dealt with in the fourth, and last, report. The format of each report will be exactly the same to make the information and comparison of species as useful as possible.

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GLOSSARY

Basic density. Green weight divided by green volume.

Cambium. A cylinder, strip, or layer of meristematic cells, which divide to give cells which ultimately form a permanent tissue. The primary cambium in the stem and root gives rise to xylem and phloem, and the secondary one produces bark.

DBH. Diameter breast height (4.5 feet).

Gelatinous fiber. Fiber, the inner wall of which is more or less gelatinous, or jellylike.

Inner bark. Tissues in the cylindrical axis of a tree immediately outside the cambium; includes the region of the secondary phloem from the cambium to the last-formed periderm.

Outer bark. Tissues in the cylindrical axis of a tree immediately outside the inner bark; includes the tissues from the last-formed periderm to the outer surface of the bark.

Parenchyma. Tissue consisting of short, relatively thin-walled cells, generally with simple pits; concerned primarily with storage and distribution of carbohydrates.

Periderm. Term applied to the cork cambium (phellogen) and the tissues (phellem and phelloderm) derived from the cork cambium.

Ray. Ribbon-shaped strand of tissue extending in a radial direction across the grain.

Resin canal. An intercellular space, often bordered by secreting cells, containing resin or turpentine.

Rhytidome. A tissue cut off outside a periderm. The cells die leaving a crust made up of alternate layers of cork and dead phloem or cortex.

Sclereid. See Sclerenchyma.

Sclerenchyma. Mechanical tissue consisting of cells with thick, lignified walls and small lumens. If the cells are elongated, they are called fibers and usually occur in bundles. When the cells are oval or rounded, they are called sclereids. They occur singly or in groups.

Secondary phloem. Inner bark.

Segregation. Removal of either the wood or bark fraction from wood/bark chip mixtures.

Separation. Detachment of bark from wood.

Sieve tube. A characteristic element of phloem. It translocates food materials synthesized in the plant. The cells are living, thin-walled and in longitudinal rows. They are connected by perforations in their transverse walls, through which pass strands of cytoplasm.

Specific gravity. Ovendry weight divided by green volume unless otherwise specified.

Storied. Arranged in tiers or in echelon, as viewed on a tangential surface or in a tangential section.

Tracheid. Fibrous lignified cell with bordered pits and imperforate ends; in coniferous wood, the tracheids are very long (up to 7+ mm) and are equipped with large, prominent bordered pits on their radial walls; tracheids in hardwoods are shorter fibrous cells (seldom over 1.5 mm), are as long as the vessel segments with which they are associated, and possess small bordered pits.

Uniseriate. Arranged in a single row, series, or layer. Also said of a vascular ray which is one cell wide in cross section.

Vessel. Composite, and hence articulated, tubelike structure found in porous wood, arising through the fusion of the cells in a longitudinal row through the partial or complete disappearance of the cross walls.

Xylary initials. The newly formed vascular tissue which conducts water and mineral salts throughout the plant and provides mechanical support.

Xylem. Wood. The vascular tissue which conducts water and mineral salts throughout the plant and provides mechanical support. It consists of vessels, and/or tracheids, fibers and some parenchyma.

APPENDIX

TABLE XXVI

BETWEEN SPECIES COMPARISONS OF WOOD/BARK ADHESION

Species	Wood/Bark Adhesion, kg/cm^2	
	Peeling Season	Dormant Season
Shagbark hickory	5.3	26.9
Eastern cottonwood	4.4	13.5
Quaking aspen	6.4	11.4
Bur oak	5.8	9.6
White birch	5.1	12.0
Sugar maple	5.8	10.1
White spruce	5.0	11.0
Slash pine	3.5	9.1
Northern red oak	2.5	8.4

TABLE XXVII

BETWEEN SPECIES COMPARISONS OF BARK STRENGTH

Species	Bark Strength, kg/cm^2	
	Inner Bark	Outer Bark
Shagbark hickory	25.0	72.7
Eastern cottonwood	17.7	4.2[a]
Quaking aspen	9.0	4.9
Bur oak	4.5	7.0
White birch	1.6	9.8
Sugar maple	1.4	4.7
White spruce	7.4	--
Slash pine	6.4	5.2
Northern red oak	2.1	4.6

[a] Strength low, test samples failed during preparation, data based upon a single test.

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